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An analysis of military use of non medical simulators has been carried out for the purpose of strategically directing the use of simulation in medicine. The United States Department of Defense has placed an increasing reliance on the use of simulators to train and sustain all manner of skills. This experience is documented by numerous studies attesting to the efficacy of trainers and the cost benefits of simulators. In addition, the range of skills to be trained is effectively broadened by the scope of situations that can be addressed by simulators and the accuracy with which performance can be measured.

Technological advances make feasible the introduction of simulation into medicine with the potential for improved training at reduced cost and reduction of medical error. Important lessons need to be learned from the military simulation experience so that the most cost-effective application of emerging technologies can be strategically sought for medical simulation. One area of particular benefit to the military medical domain will be substantial improvements in combat trauma readiness. A strategic plan for development of medical simulation in the military are advanced in the report.

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Howard R. Champion
PI - Signature

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(4) INTRODUCTION

This report provides the framework for the design and implementation of an effective, integrated program for medical simulation in the U.S. military. To provide the context for medical training, the military simulation experience has been examined to extract guidelines based on instructional value and cost savings. This has included a review of the available literature and information on the military experience using computer-based simulation trainers for flight training, ship navigation, artillery and gunnery practice, vehicle, maintenance and other applications. An effort has also been made to make a quantitative estimate of the training efficacy of simulation in the military and compare these results to other instructional approaches and strategies. The emphasis is placed on lessons that can be learned from simulation training in other domains that can be applied to the design and development of an efficacious simulation-training program in medicine. The goal is to develop a medical simulation program that can be used to train and assess the performance of combat medics, physicians, and others to increase the readiness of medical personnel in the military. The central premise of this study is that the analysis of simulation training efficacy in the military can provide useful directions for future development efforts in medical simulation. For example, many studies aimed at evaluating the effectiveness of flight simulation training have compared the amount of training time needed to perform a specific task in an airplane after either training only in an aircraft or after prior training in a simulator, an instructional measure known as transfer-of-training. Similarly, other measures such as cost effectiveness, fidelity, technology suitability, instructional design, phase of learning and other factors have been examined. There has been a huge investment over the past 30 years by the military to identify factors that make simulators effective training instruments. Taken together, these studies provide both general guidance on the design of medical trainers, as well as specific recommendations for the technical configuration of medical simulators for training medical procedures and skills. This approach emphasizes the need for matching simulation technologies with training requirements, reducing the risk of costly and ineffective applications.

Although the domain of medical simulation differs from those reviewed in this report, it is clear that a thoughtfully structured insertion of simulation into certain areas of medical practice holds substantial promise. The rapidly advancing field of simulation may well reduce the cost of training and form an effective bridge between textbook and patient, while reducing errors associated with acquisition of patient care skills. One domain that could particularly benefit is that of combat trauma readiness training.

(5) BODY

I. Background and Significance

Traumatic injury is the leading cause of death and disability up to middle age worldwide. Medical interventions are time critical and skill acquisition is of prime concern for civilian and military early care givers. A small number of key basic surgical skills are important in effectively intervening in life-threatening situations in the early phases of trauma care. They include: pressure hemostasis, endotracheal intubation, insertion of surgical airway, intravenous line insertion, central venous line insertion and relief of hemothorax or pneumothorax by needle thoracentesis or closed tube thoracostomy.

The ability of all health care practitioners to acquire these skills and sustain that expertise is increasingly limited by the opportunity to experience trauma. As a result, many practitioners have to perform such maneuvers, often for the first time unsupervised, under emergency and adverse situations on patients whose life is at risk. Currently no training environment is consistently available in which to develop or hone such skills prior to practice on a patient. The problem is acute worldwide, particularly for military personnel. Traditionally, training substitutes have centered on the use of live animals and cadavers. There is increased resistance to using the former and the latter lack the vitality essential for realistic training. The best efforts to develop simulated environments so far have been centered on rubberized mannequins, some embellished with computer-assisted mimicking of physiological functions. These too are substantially limited in their ability to provide effective training in trauma skills.

Developments in computer hardware and the availability of software such as National Library of Medicine's Visible Human dataset make it now possible to use computer graphics simulation environment to train for such skills. The added advantage of the computer graphic simulation environment is that all maneuvers can be measured and thus skills assessment can be integrated into the process of training. In addition, training at the "margins" for situations that produce error and the need for corrective action can also be modeled into the virtual scenarios. Such cannot now be done with live animals or with any fidelity in mannequin simulators. Thus, insertion of a chest tube in the wrong place, (e.g., liver), placement of a central venous line into an artery and the sequelae and instructions for such errors are all possible. The aviation analogy is that of flying a B2 bomber at 500 feet. This cannot be done live without risk, and great potential expense, but can be effectively practiced on flight simulators.

There is a clearly identified urgent operational requirement[1,2] to train combat medics, independent duty corpsmen, nurses, physician assistants, physicians, surgeons and others in the skills necessary to perform life-saving maneuvers under the extreme stress of the battlefield environment. Combat trauma medicine requires exceptional skills, including perceptually-tuned cognitive performance in a complex spatial environment, dexterous precision, steady-hand maneuvers, and continuous perceptual-motor tasks, all of which must be performed in a stressful, mission-critical environment where failure has grave

consequences. Several reports, including that of the Inspector General[1], General Accounting Office (GAO)[2] and the Armed Services Biomedical Research Evaluation and Management Committee [3], identified problems associated with training military medical personnel, suggesting that military medical personnel are poorly prepared for combat trauma. Reasons for diminished medical readiness among military personnel include a lack of exposure to severely injured patients, few personnel left with actual combat experience, and a widening gap between the minimally invasive techniques of civilian practitioners and the skills required for treating wounds such as mine injuries. These problems are exacerbated among non-physician medical personnel such as medics and corpsmen, who are responsible for early treatment of battlefield injuries.

Complex tasks in domains such as aviation and transportation have been trained for decades using computer-based simulation. Computer-based simulation is used extensively to prepare the warfighter for combat, and is now a standard part of readiness training in infantry, tank and air warfare. All branches of the armed services prioritize simulation for more efficient training with fewer resources and with less danger to personnel and the environment. The program to prepare the U.S. Army for the Twenty-First Century, Force XXI Training Program (FXXI-TP), emphasizes the use of simulators as a primary method for training. Medical simulation has been identified in the 'Joint Science and Technology Plan for Telemedicine' as a primary approach for increasing individual medical skills proficiency among combat medics, field corpsmen, physicians and other medical personnel in trauma in the military. Modern simulation technology can reproduce many of the salient features needed for effective trauma training, and is a worthy instrument for training the cognitive, perceptual and motor skills needed in medicine. The insertion of simulation into the tasks of combat readiness training in medicine is not only timely, but so overdue that it should proceed as a matter of urgency.

The recent Integrated Research Team (IRT) for Medical Modeling & Simulation meeting sponsored by the Telemedicine and Advanced Technology Research Center (TATRC) of the USAMRMC highlighted the need for an integrated approach to the development of simulation-based training for medical personnel in the military. Despite the very extensive use of simulation by non-medical DoD components, current medical simulation efforts in the military are characterized by scattered research and development efforts, university-based research without adequate involvement of the military end-user, procurement of commercial simulator products that are not well integrated into the training program, and the development of limited, single simulator solutions to meet broad training requirements. No systematic efforts have been undertaken to develop and integrate appropriate simulation technology into the medical training curriculum, and there is currently a lack of an overarching plan and system integration to match educational goals with available simulation technologies. Additionally, no efforts have been made to integrate performance metrics into existing commercial simulators for medical training.

[1] Inspector General's Report #96-168 (June, 1996).
[2] General Accounting Office (GAO) (April, 1998).
[3] Joint Science and Technology Plan for Telemedicine, Armed Services and Biomedical Research Evaluation and Management Committee (October, 1997).

Scope of this Report

The training value of simulation has generally been well established in military domains other than medicine, with skill transference demonstrable from the simulator to the real world for a diverse array of tasks. Although several current and past projects funded by the Department of Defense have focused on the development of medical simulators for training medical skills, no systematic effort has been made to introduce and establish the lessons learned from years of military simulation into the medical training arena. The present analysis sets the groundwork for the design and development of an efficacious program in medical simulation training, by importing the military simulation experience into the medical domain. Recommendations are made for the design and development of simulators for training medical personnel in the military. Commercially-available medical simulators are evaluated according to the requirements developed in this analysis.

Overview of Chapters

The first chapter of the report provides a reference source and review of studies and transfer-of-training efficacy and cost effectiveness of simulation trainers in the military. Where applicable, a meta-analysis has been performed to quantify the results from a number of different studies. In many instances, methodological problems have limited this analysis, and more qualitative descriptions and tabulated results have been provided.

The second chapter of the report provides recommendations and guidelines for the design of medical simulation trainers based on the results of the meta-analysis and the experience with military simulators. Priority is placed on simulation systems that train perceptual and motor skills through the use of Partial Task Trainers (PTT) that are most relevant for procedural training in medicine.

The third chapter of the report provides a strategic plan for implementation of medical simulation-based training in the military. A review of current efforts in medical simulation, both in civilian and in military sectors, is to be examined in light of the current findings. An assessment is made of the appropriate use of technology, medical utility and applicability to combat trauma training. This chapter outlines a plan for the development of an effective program in medical simulation based on the current study recommendations.

II. Literature Survey

An extensive search of the literature revealed a total of 141 publications that were considered relevant for the present study, including technical reports, scientific papers, and case studies, spanning more than fifty years, from 1940's to the present (see Bibliography). For the meta-analysis, special emphasis was placed on reviews of the literature that summarized transfer effects of simulation training. Other publications included studies of cost efficacy, technical description of simulators and features, and literature reviews.

This chapter is broken down into 3 sections: (A) Summary of Key Findings, (B) Cost Efficacy of Military Simulation, (C) Synopses of Selected Publications, which provides the reader a summary of important publications emphasizing key points in the development of guidelines based on the military simulation experience, (C) Literature Database, which lists the publications used in this first part of the analysis, with topics identified including training efficacy, performance assessment, fidelity and part-task training, and (D) Preliminary Results from the quantitative Meta-Analysis.

A. Overview

This analysis has identified and examined four key factors in the military and flight simulation literature, which are considered critical for the successful development and implementation of medical simulation-based training in the military. These factors include:

- Training Efficacy – The degree to which the skills trained in the simulation environment transfer to real world skills.
- Performance Assessment – Functions embedded into the simulator, which can track and measure the performance of the simulator operator.
- Fidelity – The extent to which the simulator reproduces the physical characteristics of the real world procedure, equipment or skill being simulated.
- Part-Task Training – Selective focus on the training of specific critical skills deconstructed from larger tasks.

<u>Training Efficacy</u>

A commonly used measure of simulation-based training efficacy is "transfer", that is, how much student performance can be transferred from the simulator to actual, real world procedures. This can be expressed as a transfer effectiveness ratio (TER), which has been reported for a number of cases in the literature.

There are several ways in which simulation-training efficacy can be measured. Using direct simulator versus traditional method testing, the performance of a student trained only on a simulator can be compared to a control student tested using traditional mentoring procedures. Within-simulator performance evaluation is another common approach used

for testing the training effectiveness of simulators. These data are then evaluated using statistical tests designed specifically to compare simulation performance with actual performance in the real world. These data can then be used to determine transference rates.

An important standard that should be mentioned at this point is 'transference rate". A general determination of transference rate for flight simulators can be made as follows:

<u>Transfer Effectiveness Ratio (TER)</u>

$$A - As/S = TER$$

A = Time without simulator

As = Time after simulator

S = Simulator time

The literature shows that, in general, the transference rate for a flight simulator is 0.48 - that is, 60 minutes using a flight simulator is worth 30 minutes flying an airplane in terms of training efficacy (Orlansky et al, 1994).

Many investigators, including ourselves, have found simulation to be an extremely effective training instrument (Advisory Group, 1980; Carreta and Dunlap, 1998; Hays and Singer, 1989; Hayes et al, 1992a; Hays et al, 1992b; Jacobs et al, 1990; Knerr et al, 1986; Moroney and Moroney, 1998; Orlansky and String, 19791 Orlansky et al, 1994). These include studies in which a meta-analysis of the simulation literature has been performed to provide a more sensitive measure of the benefits of simulation training, using "field effects analysis" and other statistical methods. Although there is some controversy surrounding the validity of data pooled in such a manner, our results and those of many other investigators show that, in general, simulators provide an extremely valuable training effect comparable to training using actual equipment and real world procedures.

<u>Performance Assessment</u>

There are numerous studies that show performance assessment is critical to effective simulator training (Benton et al, 92; Caro and Isley, 1966; Caro et al, 1984; Connolly et al, 1989; Copenhaver et al, 1996; Dohma, 1995; Guckenberger et al, 1993; Hettinger et al, 1994, 1995; Jorna et al, 1992; Jacobs et al, 1990; Marcus and Curran, 1988; McCaulley and Cotton, 1982; Orlansky et al, 1997; Roscoe and Williges, 1980; Sterling, 1993a,b; Spears, 1983; Thomas et al, 1990; Westra et al, 1981; Westra et al, 1988). Performance measures may include simple functions such as listing the order in which a user activates a sequence of switches, or may involve sophisticated, computer-based systems that can evaluate users in a complex, distributed virtual environment. Metrics may include measures such as timing, accuracy, tissue damage, instrument handling, applied force, cognitive decision-making and others.

In military simulation, several factors have been found to important for implementation of successful performance measurement systems in simulation. First, users benefit from being able to compare their performance against other users of the simulator, for example, other trainees or expert users. Second, performance measures on the simulator must relate to performance on the real world procedure being simulated. Finally, users must be motivated to perform well on the simulator. Thus, successful performance on the simulator should be tied to successful completion of the training requirement. In addition, features that provide real-time performance feedback to the user have been shown to enhance training.

Fidelity

Fidelity is the degree to which the simulator reproduces the actual, real-world procedure being simulated. Hays and Singer (1989 defined fidelity as:

"...the degree of similarity between the training situation and the operational situation which is simulated."

The bulk of data show that physical (also known as 'objective') fidelity is not a requirement for successful simulation-based training (Advisory Group, 1980; Benton et al, 1992; Boldovici, 1987; Carretta and Dunlop, 1988; Copenhaver et al, 1996; Cyrus, 1978; Dixon and Curry, 1990; Dixon et al, 1990; Dohma, 1995; Durall et al, 1978; Edwards, 1986; Hays and Singer, 1989; Hays et al, 1992a,b; Knerr et al, 1986; Lees and Bussolari, 1989; Lintern, 1980; Lintern et al, 1987; Lintern et al, 1989; Lintern et al, 1990; Lintern et al, 1997; Loesch and Waddell, 1979; Martin, 1981; Martin and Waag, 1978a,b; Martin and Cataneo, 1982; McDaniel et al, 1983; Micheli, 1972; Montemerlo, 1977; Moroney and Moroney, 1998; Nataupsky et al, 1979; Orlansky et al, 1997; Pfeiffer, 1983; Rankin et al, 1984; Ryan et al, 1978; Voss et al, 1970; Waag, 1980; Westra et al, 1981; Westra et al, 1982; Westra et al, 1988; Westra, 1982).

Students trained using low fidelity simulation can perform as well or better than students trained using high fidelity simulation:

- Caro (1988) showed that for novice training, simple wooden mockups were as effective as sophisticated cockpit simulators for training.

- Warren and Riccio (1985) showed that providing irrelevant stimuli in the context of a higher fidelity simulation actually made task learning more difficult as the novice trainee has to learn to ignore these stimuli.

- Kass, Herscheler and Campanion (1991) showed that students trained in a "reduced stimulus environment" that presented only task-relevant cues performed better in a realistic battle field test than those who were trained in the battle field test condition.

- Lintern, Roscoe and Sivier (1990) showed that naive students trained without crosswinds in a simulated landing task performed better than students trained with crosswinds in landings that have crosswinds.

- Lintern and colleagues (Lintern et al, 1990b: Lintern and Garrison, 1992; Lintern et al, 1997) found that pictorial displays were more effective than symbolic displays in training landing skills, but increases in scene fidelity either had no effect on performance or actually reduced performance in some cases by distracting the trainee.

Although the overwhelming preponderance of data from military, flight and medical simulation show that simulators do not have to exhibit high fidelity to be useful training instruments, they do have to have face validity for the end-user. Face validity is the degree to which the simulator appears 'genuine' and is adopted by the end-user. Often simulators will be used enthusiastically by trainees if they are endorsed by known content experts, and/or have a demonstrable ability to improve skill, even if the simulator appears unrealistic.

A classic case about simulation fidelity was the controversy about the need for motion platforms to realistically reproduce aircraft motion in flight simulation training. These motion platforms are very expensive, but are enthusiastically embraced by users as providing a much more realistic training experience then can be provided by static flight simulators. However, as reviewed recently in Moroney and Moroney (1998), the majority of the data show that, for most tasks that have been studied, motion platforms do not provide any additional instructional advantage over static systems. Boldovici (1992) interviewed 24 experts in the field and came to 11 conclusions about the need for motion platforms. He found, among other results, that greater transfer-of-training can be achieved by less expensive means than using motion platforms. Therefore, if cost is a requirement, motion platforms will never demonstrate an advantage. User's and buyer's acceptance is not an appropriate reason for the use of motion platforms.

The point is that the emphasis in simulator design and development must be focused on an accurate definition of the skills to be trained by the simulator, and not creation of the technically most realistic trainer possible. If the skills to be trained are adequately addressed, then low fidelity simulators may perform adequately, and the degree of fidelity required can be evaluated using the simulator.

Several authors have suggested that simulator fidelity be matched to the stage of learning: cognitive (initial), associate, and autonomous. Low fidelity simulators have been proven to be effective for initial training and sustainment training, whereas higher fidelity trainers may be more appropriate for autonomous learning.

Part-Task Training

The bulk of modern simulation training data, part-task training is more effective for training difficult and "high performance" skills than is whole task training (Adams et al, 1962; Advisory Group, 1980; Aukes and Simon, 1957; Bailey et al, 1980; Gray, 1979; Kilion et al, 1987; Knerr et al, 1986; Mattoon, 1994; Naylor, 1962; Orlansky et al, 1994; Sheppard, 1985; Wightman, 1985; Wightman and Sistrunk, 1995; Wray, 1987).

Knerr et al (1986) reviewed the literature on flight training with regard to the use of simple, low fidelity trainers such as the Cockpit Procedures Trainer (CPT) and their utility for initial training and sustainment. The CPT is a part task trainer that is simple, low fidelity and inexpensive, and represents an early model for part task trainers that can be effective in terms of training value and cost. Partitioning a large, complex task into complete, coherent parts did not disrupt learning and subsequent performance of the parts. However, it was felt that students needed to train a small amount on the entire procedure to learn time-sharing between individual parts.

- Part-task training of a skill that received very little practice in flight can be highly cost effective.

- CPTs (simple, low fidelity part-task trainers) have some value for *ab initio* training as long as student pilots have some opportunity to practice the whole task so that can acquire time-sharing skills.

- CPTs (simple, low fidelity part-task trainers) are very effective at sustaining procedural skills that are otherwise susceptible to forgetting over periods of no practice.

- CPTs (simple, low fidelity part-task trainers) may be effective for transition training of experienced pilots on the procedural aspects of new aircraft.

From these and other data, it is clear that part-task trainers can be used:

- To train on complex procedures that require extensive practice to achieve proficiency, where critical steps (tasks) require "high performance"

- For sustaining training of procedural tasks, and

- To provide initial training on new procedures and tasks.

One other general finding is that part-task trainers do not require high fidelity, in part, because only a portion of the entire task needs to be simulated, and the emphasis can be placed on training a specific, highly critical skill, not on reproducing the entire procedure from start to finish.

B. Cost Effectiveness

Over forty studies have been identified that have directly or indirectly examined the cost savings realized with the use of simulation-based training. In many case, cost savings have been measured in the context of training efficacy, where "student time savings" and other benefits are translated into monetary assets. Because simulators provide an opportunity for training without incurring the cost of actually operating expensive equipment such as airplanes, ships and tanks, the majority of savings accrue from decreases in operating expenses. Other savings may be realized from decreased impact on the environment and other resource savings such as lowered personnel deployment.

A general finding is that military training using simulators costs approximately 10% of the cost of training using actual equipment. A comparison of the operating costs of 42 military flight simulators shows that the costs of using the simulator are always less than that of using the actual equipment, with operating costs ranging from 8 to 50% that of the actual equipment. Acquisition and life cycle costs are about one half that of the actual equipment and the amount of annual savings can be amortized in from 2 to 4 years. Figure #1 shows examples of the amortization of selected flight simulators.

Figure #1: Examples of Cost and Amortization of Selected Training Simulators

Simulator	Procurement Cost	Savings per Year	Time to Amortize Costs
Coast Guard, HH-52A HH-3F	$3.1M	$1.5M	2.1 years
Navy, P-3C	$4.2M	$2.5M	1.7 years
Airline, 1A	$17.5M	$25.3M	8.3 months

From Orlansky and String (1977)

For all military simulators that have been examined for both cost and effectiveness, when students are tested on actual equipment, training with simulators is as effective as training on actual equipment. Many studies aimed at evaluating the effectiveness of simulation training have compared the amount of training time needed to perform a specific task in an airplane after either training only in an aircraft or after prior training in an aircraft. This can be expressed as a quantitative value as the Transfer Effectiveness Ratio (TER). For example, Figure #2 shows the median of 34 TERs compiled from 22 flight simulation studies is 0.48, meaning that about one half hour is saved in the air for every prior hour that is trained on the same task in a simulator.

Figure #2: Cost Savings Realized with Military Flight and Maintenance Simulators

Simulator	Transfer Effectiveness Ratio	Student Time Savings	Acquisition Savings	Operating Savings	Life-Cycle Cost	Amortization
Flight	0.48	50%	30-65%	10%	65%	2 years
Maintenance	0.60	20-50%	20-60%	50%	40%	4 years

(Adapted from Orlansky et al, 1994)

It should be noted that although simulators offer cost savings compared to training using actual equipment, simulators also have significant maintenance and operational costs. It has been estimated that as much as half of the DoD budget for simulation is earmarked for ongoing support and service of simulation training systems (Strachan, 1998).

One recent study of a large, distributed training exercise compared personnel, operating and per person costs between simulation and real world training exercise. Components included aircraft and battlefield forces from the Army, Marines, and Air Force, participating in the Multi-Service Distributed Training Testbed (MDT2) for Close Air Support. In this case, performance using simulation training was validated using process-oriented measures, outcomes assessment and after action review. This study shows another example of relatively cost savings associated with simulation training, as shown in Figure #3.

Figure #3: Examples of Cost Savings Realized with a Large, Multi-Service Training Exercise

Category	Simulation Costs	Field Exercise Costs	Cost Savings (Per Cent)
Personnel – Base	$85,000	$493,000	$408,000 (83%)
Operating – Base	$182,000	$2,404,000	$2,222,000 (92%)
TOTAL – Base	$267,000	$2,897,000	$2,630,000 (91%)
Personnel – Aircraft	$22,000	$299,000	$277,000 (93%)
Operating – Aircraft	$24,000	$126,000	$102,000 (81%)
TOTAL – Aircraft	$46,000	$425,000	$379,000 (89%)
Per Person	$3,600	$11,800	$8,200 (69%)

(Adapted from Orlansky et al, 1997)

Another recent example of cost savings realized by using training simulators is provided by the M1 and M1A2 Tank Driver Trainers (TDT). These simulators provide initial and transition driver training for M1 Abrams Armor crewman. The simulator consists of a driver training station, instructor/operator station, image display, audio system, computer system, and a fully integrated motion system. A real-time color computer, image generation sub-system provides visual scenes to the driver through the periscope or on a screen for out-of-hatch training. The instructor station is capable of selecting a visual scene, viewing it, monitoring each trainee's performance, and introducing malfunctions and emergency control situations. Eighteen systems M1 TDT's and two M1A2 TDT's have been fielded to Ft. Knox, Kentucky.

The savings realized by the TDT training compared to real world training have been characterized by STRICOM. From March 1993 to 5 January 1998, TDT operators at Ft. Knox logged 599,129 simulated miles. Driving logs indicated that 22,625 runs were made on the M1 TDT by driver trainees and 329 runs were driven on the M1A2 TDT by advanced driver trainees. The typical M1 Training Tank costs $155/mile to operate whereas the Tank Driver Trainers cost $5.44/simulated mile. Based on these figures, the cost of operating the 20 trainers was found to have been $3,240,902. The cost savings realized by using TDT simulators for training instead of using M1 and M1A2 Training Tanks was calculated to have been $92,341,870, during the period from 1993 - 1998. The cost avoidance was 162% of the total project development cost of $57M.

C. Synopses of Selected Publications

This section provides a synopsis of publications that were considered noteworthy examples of contributions to the literature in this domain. These include reviews, original scientific research papers and other publications on transfer-of-training efficacy using simulation, cost efficacy, fidelity and part task training, as well as other relevant areas of particular interest to the development of guidelines based on the military simulation experience.

The synopses are listed in alphabetical order by first author. The report from the NATO Advisory Group was chosen because it provides a consensus view from military and civilian simulation experts of member countries that fidelity needs to be defined in terms of functional requirements, that is, the extent that simulation produces the desired training effect, not on absolute physical characteristics. Carreta and Dunlap (1998) was chosen because it provides specific examples from the naval air and jet carrier landing literature on the ability of low fidelity visual simulators to provide as effective a training on certain tasks as higher fidelity displays. Copenhaver et al (1996) provides another example of simulator fidelity related to firing skills in the Distributed Interactive Simulation (DIS) environment. Knerr et al (1986) provides a modern review of the importance of part task trainers for procedural training, emphasizing the need to look at the stage of learning (cognitive, associative, autonomous) to appropriately target simulator development. Moroney and Moroney (1998) is a recent review of flight simulation, emphasizing the attributes of flight simulation, summarizing the controversy surrounding motion platforms and the utility of low fidelity systems for training, as well as providing information on advanced instructional training. Orlansky et al (1994) is a landmark study looking at the cost efficacy of simulation in the military, and providing budgetary information and case examples from all services from data collected in the early 1990's – in some ways the current study is an update of their report. Sterling (1996) was selected because it emphasizes the importance of case studies for simulation-based training. Taylor et al (1997) was included because it shows the efficacy of low fidelity PC-based trainers, and Westra et al (1988) shows the value of low fidelity visual displays for simulation training.

Report: "Fidelity of Simulation for Pilot Training"

Authors: Advisory Group for Aerospace Research and Development

Organization: Advisory Group for Aerospace Research and Development, NATO

Publication Date: 1980

Journal/Technical Report: DTIC ADA 096825

This report provides a consensus review of the fidelity requirements for flight simulation. This was a NATO-sponsored working group consisting of U.S. and European flight simulation, human factors and technology experts. Recommendations were prepared for broader dissemination to member communities.

(a) Definition of Simulator Fidelity

The report describes 2 different types of fidelity:

(1) Objective fidelity refers to the degree to which a simulator would be observed to reproduce its real-world counterpart aircraft, in flight, if its form, substance, and behavior were sensed by a non-physiologic recording system aboard the simulator.

(2) Perceptual fidelity refers to the degree in which the simulator provides a psychological and physiological viewpoint to the trainee such that the trainee perceives the simulator to reproduce the real-world counterpart aircraft.

(a) Pilot Training and Simulator Fidelity

The overwhelming preponderance of evidence from the literature and the results of the working group's analysis is that simulators need to be designed according to criteria other than an actual physical reproduction of the aircraft.

Objective fidelity should not necessarily be a goal of simulator design and development, because:

- It is usually requires great expense to develop high fidelity simulations of actual aircraft.
- High fidelity simulation is not a requirement for effective training. Low fidelity simulators can be extremely effective training devices.

(b) Training Effectiveness Models in Flight Simulation

Training effectiveness is a determination of whether a device has an effect on training performance.

Review of Training Effectiveness Models

(1) *Transfer-of-training model*: This model is the study design most appropriate to determine whether simulator training has improved subsequent operational performance. This model typically involves 2 groups of trainees: an experimental group which receives simulator training prior to further training or performance testing in the aircraft, and a control group which receives all of its training in the aircraft. This design permits differences in user performance in the aircraft to be attributed to simulator-based training of the experimental group.

(2) *Self-control transfer model*: This is variation of the transfer model in which operational training is interrupted for simulator training, and user performance before simulator training can be compared with performance after simulator training to determine the effects of simulator training. Thus, the experimental group serves as its own control group.

(3) *Pre-existing control transfer model*: This design model may be used when student performance from an old or existing training program can be compared to performance following simulation training, obviating the need for a control group. However, differences in performance between the two groups may result from changes that have occurred in the population during the time between which the experimental and control groups were drawn.

(4) *Uncontrolled transfer model*: This model may be necessitated when it is not possible to configure a control group. Although this is problematic from an experimental point of view, it may be unavoidable in some cases, and may be desirable to use such data in cases such as space travel where important safety issues may present barriers to more valid experimental design considerations. Data gathered from such studies may have significant weight, but must be manipulated using appropriate statistical methods and recognition of limitations.

(5) *Simulator-to-simulator transfer model*: This model involves measurement of performance in a second simulator following training in the first simulator. The use of this model is only appropriate when the second simulator is used as the criterion vehicle.

(6) *Backward transfer model*: In this model, performance is measured in a simulator following training in a real world task. Thus, expert performers are used to assess the training effectiveness of a simulation trainer. Care must be taken using this model because: (1) experienced personnel already proficient at an operational task may have highly generalized skills not possessed by recent program trainees or (2) the simulator

may be designed to elicit a particular set of behaviors exhibited by skilled performers but not by novice trainers.

Other design models:

- Simulator performance improvement model
- Simulator fidelity model
- Simulator training program analysis model
- Opinion survey model (*note: this has shown to be unreliable*)

Choice of Training Effectiveness Model

The appendix lists several key issues, which are addressed using the training effectiveness models. These include:

- How long it takes to learn a task in the simulator
- How effectively the task is subsequently performed in the aircraft
- How much training normally conducted in the air is performed on the simulator

These essential questions depend on having suitable measures, including:

- The amount of learning achieved in the simulator
- The amount of learning which transfers to the aircraft
- The amount of savings made as a result of the simulator

Report: "Transfer of Training Effectiveness in Flight Simulation: 1986 to 1997"

Authors: Carreta, T.R. and R.D. Dunlap

Organization: Warfighter Training Research Division, Air Force Materiel Command

Publication Date: September 1998

Journal/Technical Report: AFRL-HE-AZ-TR-1998-0078

This report reviews and summarizes literature on transfer of training from the simulator to the aircraft, including 13 papers directly focused on transfer efficacy.

(a) Historical Perspective

The authors cite the work of Hays et al (1992), who performed a meta-analysis and review of the literature from 1957 to 1986. They looked at 26 studies, 19 using jet aircraft and 7 involving helicopters. Hays et al (1992) found that:

- Flight simulators consistently lead to improved training effectiveness for jet pilots relative to training in aircraft only. However, this was not found to be significant for helicopter pilots.

- Motion cueing was not found to enhance jet pilot training, and in some cases, it actually may have led to less effective training.

- Training effectiveness was strongly influenced by the task to be trained and the amount and type of training provided. For example, simulators were found to be more effective for training takeoff, approach to landing and landing than for all pilot tasks combined.

(b) Recent Studies

Landing skills

The most frequent use of simulators was for landing skills. Lintern et al (1990a) found that landing skills learned in a simulator could be transferred to aircraft landing. The students trained in the simulator flew 1.5 fewer pre-solo hours than the control group of students.

Another group of studies from Lintern and colleagues (Lintern et al, 1990b: Lintern and Garrison, 1992; Lintern et al, 1997) found that pictorial displays were more effective than symbolic displays in training landing skills, but increases in scene fidelity either had no effect on performance or actually reduced performance.

Radial bombing accuracy

Lintern et al (1987) in a quasi-transfer study of air-to-ground attack skills tested the effect of scene detail on performance. Dive pitch error was reduced when scene detail was increased, but profound effects were not apparent.

Lintern et al (1989) examined the effect of scene detail, FOV and number of simulator trials on performance in an air-to-ground mission. Increases in scene detail and FOV had no effect on performance of radial bombing accuracy. Increases in simulator trials did increase performance, but this effect was negligible after 24 trials.

Instrument and Flight Control

Pfeiffer et al (1991) found that simulated instrument training was transferable to both instrument and contact flight performance. A test of the validity of the ability of simulator performance to predict actual, real-world performance was significant, for both instrument (r =.98) and contact (r =.95) flight.

Report: "Training Effectiveness Evaluation of an MLRS Fire Control Panel Trainer Using Distributed Interactive Simulation"

Authors: Copenhaver, M.M., H.L.F. Ching and L.G. Pierce

Organization: CAE-Link Corporation

Publication Date: March 1996

Journal/Technical Report: ARL-CR-294 / NTIS ADA307678

This study performed a training effectiveness evaluation of a multiple launch rocket system (MLRS) fire control panel trainer (FCPT) using the distributed interactive simulation (DIS) environment. This effort was undertaken to show, in a broad way, to demonstrate that training devices can be integrated into a DIS environment with actual military command and control devices, and performance data could be captured and analyzed from a training device in the DIS environment.

The results showed that soldiers could be trained effectively in the DIS environment and that this environment could collect performance in an automated fashion. Performance was increased over number of trials. On average, soldiers were able to meet the criterion level of performance after the second scenario run, with students committing fewer errors as the training runs progressed. Questionnaires assayed student's opinions about the usefulness and attractiveness of the DIS training environment. In general, the students had a positive attitude about the experience.

Of particular relevance was the student's regard of the low fidelity of the FCPT screen display. Like the actual MLRS FCP display, the FCPT displayed orange characters on a dark background, however the FCPT uses a conventional color monitor and looked somewhat different from the actual screen. Thus, fidelity was not a requirement in this study.

Report: "Simulation-based Research in Part Task Training"

Authors: Knerr, C.M., J.E. Morrison, R.J. Mumaw, D.J. Stein, P.J. Sticha, R.G. Hoffman, D.M. Buede and D.H. Holding

Organization: Human Resources Research Organization for Air Force Human Resources Laboratory

Publication Date: October 1986

Journal/Technical Report: DTIC AD-B107 293

This was the most thorough and authoritative study on the use of part task simulators for training complex procedural skills. The goal of this study was to developed guidelines to deconstruct complex flight tasks into parts that can be effectively trained using less expensive simulation trainers. The deliverables included a literature review and feasibility study on part-task training. The investigators developed a prototype decision-support system to be used as a basis for the design of training systems in the Air Force.

(a) Review of Part-Task Training Research

<u>Early research (1910 to 1930)</u>

Naylor (1962) discussed the early literature on part-task training. His summary of the early research concluded:

- Whole-task training tends to be superior to past-task training when:
    - The task is highly integrated (parts are not easily separated)
    - A large amount of training is required
    - Initial practice is distributed
    - Retention is the critical variable
    - Training time is not critical

- Part-task training tended to be more effective than whole task training when:
    - The task is critical
    - Training time is critical

<u>Research Results from 1930 to 1960</u>

The authors again quote the work from Naylor (1962) who organized the literature based on high, medium and low task organization and task difficulty determined by estimated time to learn the task (low = 1 hour or less to learn; medium = 1 hour to 1 week to learn; high = more than 1 week to learn the task).

Naylor concluded the following from this era of research on part-task training:

- Whole task training becomes more efficient as the task becomes more highly integrated (organized) (Knapp, 1963; Woodhead et al, 1979).

- Part-whole efficiency is task-specific since task variables and method interact (based on Cook, 1937).

- Whole task training is better for highly organized tasks.

- Part task training is best for difficult tasks.

<u>Development of Complex Perceptual-Motor Skills</u>

Of special relevance to both aviation and medicine is the development of continuous perceptual-motor tasks. Fitts and colleagues (Fitts, 1964; Fitts et al, 1961; Fitts and Posner, 1967) developed the three-stage model of complex skill acquisition including cognitive, associative and autonomous stages. These are summarized by the authors as follows:

(1) *Cognitive Stage*: The first stage involves "intellectualization" of flying skills, which shortens the amount of time needed for solo flight. Demonstrations and verbal analyses are more effective training techniques during this stage, as the learner attends to cues, events and responses that later may go unnoticed. According to Fitts, during the stage the learner is laying the framework or 'bauplan' that is a cognitive way of organizing the various invariant subroutines that must be coordinated during the actual performance of the complex procedure. Intellectualization during this stage is the initial step for execution of subsequent procedures that may share elements of the task being trained.

(2) *Associative ('fixation') Stage*: The second stage involves consolidation of existing skills and their reassembly into new patterns. Correct patterns are instantiated by continuous practice and errors are reduced. Critical training issues include the use of part-task training of component skills, where invariant subroutines can be identified.

(3) *Autonomous Stage:* The final stage of learning involves increases in speed and accuracy. Performance appears to be less controlled by cognitive function, and less dependent on external feedback and more on proprioceptive feedback. Skills become automated to the extent that the operator can "multi-task", eg, combine performance of a learned skill along with performance of other functions.

<u>Use of Low Fidelity Simulators for Initial and Sustainment Training for Procedural skills</u>

The authors review the literature on flight training with regard to the use of simple, low fidelity trainers such as the Cockpit Procedures Trainer (CPT) and their utility for initial training and sustainment. The CPT is a part task trainer that is simple, low fidelity and

inexpensive, and represents an early model for part task trainers that can be effective in terms of training value and cost. The results of studies from several investigators (Adams and Hufford, 1962; Adams, 1960). The results of these studies show that:

Partitioning a large, complex task into complete, coherent parts does not disrupt learning and subsequent performance of the parts. However, students need to train a small amount on the entire procedure to learn time-sharing between individual parts.

- Part-task training of a skill that received very little practice in flight can be highly cost effective.

- CPTs (simple, low fidelity part-task trainers) have some value for *ab initio* training as long as student pilots have some opportunity to practice the whole task so that can acquire time-sharing skills.

- CPTs (simple, low fidelity part-task trainers) are very effective at sustaining procedural skills that are otherwise susceptible to forgetting over periods of no practice.

- CPTs (simple, low fidelity part-task trainers) may be effective for transition training of experienced pilots on the procedural aspects of new aircraft.

<u>Cognitive Pre-Training May be Useful for Skills Training</u>

Results from Smith (1984) and others have determined that cognitive pre-training, consisting of instruction prior to skills training, can enhance performance. Studies have found that:

- Cognitive pre-training is an effective and inexpensive way to impart knowledge required for task performance. The benefit of cognitive pre-training decreases as non-pretrained pilots acquire experience in the flying task.

- Maximum benefit is gained when cognitive pre-training is presented before skills training – interspersion may inhibit skill acquisition.

- Cognitive pre-training should be simple and direct – overly complex information may inhibit skill acquisition.

<u>Perceptual Pre-Training May be Helpful if Applied in an Appropriate Manner</u>

Many investigators have tried perceptual pre-training using mostly visual recognition tasks, such as landing orientation and aircraft identification, and these have proved useful under the following conditions:

- Critical and/or distinctive perceptual cues have been identified in the skills to be performed.

- The stage of learning (cognitive, associative or autonomous) when dependency on these cues becomes important.

- When important cues are not known or take place over a long period of time, the stimulus should be modified for training (compress events or augment cues).

(b) Conclusions from Literature Review

The bulk of recent flight simulation training data shows that part-task training is more effective for training difficult and "high performance" skills than is whole task training. These skills require more than 100 hours to achieve proficiency, where experts perform qualitatively different from novices, and where a substantial proportion of learners fail to achieve proficiency.

Report: "Flight Simulation"

Authors: Moroney, W.F. and B.W. Moroney

Organizations: University of Dayton and University of Cincinnati

Publication Date: 1998

Journal/Technical Report: Chapter in Handbook of Aviation Human Factors, (Eds, Garland, D.J., J.A. Wise, V.D. Hopkin), Erlbaum, Inc, New York.

This excellent chapter reviews a large body of work in flight simulation, addressing a wide variety of current, historic and emerging areas with a special emphasis on human factors. Both advantages and disadvantages of flight simulators are addressed (adapted from Moroney and Moroney, 1998);

Advantages of Flight Simulators

- Available 24 hours a day for training
- Can provide training time in new systems and not-yet existent aircraft
- Only way to teach some dangerous flight maneuvers
- Simulator usage reduces "wear and tear" on actual aircraft
- Provide standardized training environments with identical flight dynamics and environmental conditions
- Mistakes can be practiced for future avoidance
- Simulators provide performance measurement, including performance comparisons, performance and learning diagnosis and performance evaluation

Disadvantages of Flight Simulators

- Performance in simulator may not reflect performance in real world, because stress levels may be lower, or crew expects emergencies events to occur during simulation.
- Performance in simulators does not reflect the fatigue or boredom encountered during long hours of flying – thus, simulator performance may be better than in actual flight.
- Some simulators, such as those with motion platforms, may require expensive overhead, facilities and maintenance.
- When used excessively, simulators may negatively influence morale and retention ("I joined to fly airplanes, not simulators").

(c) Training Efficacy

The authors review the literature on cost effectiveness and training efficacy. In a discussion of previous reports reviewing transfer-of-training studies, the authors point out that the

overall preponderance of evidence shows that simulators reliably produce superior training compared to aircraft-only training (see also Jacobs et al, 1990).

Strategies for quantifying training transfer in simulation include the Transfer Effectiveness Ratio (TRE), Incremental Transfer Effectiveness Functions (ITEF) and Cumulative Transfer Effectiveness Functions (CTEF). These can all be used to measure how the desired task in the aircraft is enhanced by learning on a simulator, usually expressed in terms of time saved as a portion of actual flying experience.

(b) Fidelity

The authors review the work of Hays and Singer (1989), who have defined fidelity as:

> "...the degree of similarity between the training situation and the operational situation which is simulated. It is a two dimensional measurement of this similarity in terms of: (1) the physical characteristics, for example, visual, spatial, kinesthetic, etc; and (2) the functional characteristics, for example, the informational and stimulus-response options of the training situation".

The authors point that usually simulation developers and regulators usually emphasize the need to develop the physical characteristics, whereas trainers and scientists usually emphasize the need for development of the fidelity of the functional characteristics. Hays and Singer (1989) have emphasized that simulator fidelity should be matched to the stage of learning, type of task and type of task analysis:

Stage of Learning – These have been identified as cognitive phase, associative phase and autonomous phase (Fitts, 1962), roughly corresponding to the "see one, do one, teach one" so popular in medical education (Higgins et al, 1997). The authors argue that simulator fidelity should match the stage of learning as follows (adapted from Moroney and Moroney, 1998; Hays and Singer, 1989):

Stage of Learning	Characteristics	Simulation Fidelity Requirements
Cognitive phase	Novice attempts to understand the task, the expected behavior, sequence of procedure, and identification of relevant cues. Instructions and demonstrations are most effective during this phase.	Low
Associative phase	Skills emerge, errors gradually diminish and common features among different situations are recognized. Hands-on practice is most effective during this phase.	Low to Moderate; Part Task Trainers
Autonomous phase	Learner's performance becomes automatic,	Moderate to High:

integrated and efficient. Student can learn new skill while performing previously acquired skill.	Whole Task and Mission Training

Students trained using low fidelity simulation can perform as well or better than students trained using high fidelity simulation:

- Caro (1988) showed that for novice training, simple wooden mockups were as effective as sophisticated cockpit simulators for training.

- Warren and Riccio (1985) showed that providing irrelevant stimuli in the context of a higher fidelity simulation actually made task learning more difficult as the novice trainee has to learn to ignore these stimuli.

- Kass, Herscheler and Campanion (1991) showed that students trained in a "reduced stimulus environment" that presented only task-relevant cues performed better in a realistic battle field test than those who were trained in the battle field test condition.

- Lintern, Roscoe and Sivier (1990) showed that naive students trained without crosswinds in a simulated landing task performed better than students trained with crosswinds in landings that have crosswinds.

Type of Task: The authors also emphasize that the type of task to be trained is very important for determination of fidelity requirements. For example, a cognitive (information processing) task may benefit from a simple flow diagram for training, whereas whole task training may require higher fidelity simulation.

Motion Versus No-Motion Controversy

One of the most startling findings of several researchers has been the observation that the simple, inexpensive flight simulators provide the same training efficacy as more expensive and sophisticated flight simulators that contain motion platforms. This was counterintuitive to the notion that the addition of complex motion would provide training with more "face validity".

The following examples, provided by the authors, demonstrate the results of several studies showing that motion does not, in general, contribute to more effective learning, and may hinder training in some cases. This is obviously still a somewhat controversial finding, given the military and commercial investment in motion systems and the obvious increase in face validity that these systems provide for the user. Still, the data show that the higher fidelity motion-based simulators do not enhance training for many flight tasks:

- Martin and Wagg (1978a, 1978b) showed that for basic contact and aerobatic maneuvers, students trained in either fixed or motion platform-based simulators performed equally well, and better than students trained in an actual T-37 aircraft.

- Martin (1981) reviewed several studies, and concluded that it was not cost-effective to procure post-synergistic motion platforms to train pilots in contact skills.

- Jacobs et al (1990) conducted a meta-analysis of the flight simulation literature, and concluded that, for jet aircraft, when looking at all tasks and not specific tasks, motion cueing did not add to simulator effectiveness and in some cases may have reduced the effectiveness of the simulator.

- McDaniel, Scott and Browning (1983) reported that for certain tasks, such as free-stream recovery, aircraft stabilization equipment off and coupled hover, benefited from motion, whereas takeoffs, approaches and landings did not.

- Boldovici (1992) interviewed 24 experts in the field and came to 11 conclusions about the need for motion platforms. He found, among other results, that:

    1. Transfer-of-training studies are insufficient to support decisions about the need for motion platforms.
    2. Greater transfer can be achieved by less expensive means than using motion platforms. Therefore, if cost is a requirement, motion platforms will never demonstrate an advantage.
    3. User's and buyer's acceptance is not an appropriate reason for the use of motion platforms.
    4. In both military and commercial arenas, buyers may have more incentive to buy more expensive motion platforms rather than less expensive systems because it will enhance job advancement by working on a higher tech project.

(c) Advanced Instructional Features

AIF in flight simulation includes record, pause slow motion and playback (VCR effects), Above Real-Time Training (ARRT), "backward-chaining" and other approaches. Appropriate use of AIFs in flight simulation can greatly enhance learning. For example, Guckenberger, Uliano and Lane (1993) evaluated the performance of pilots who were trained using ARRT in an F-16 part task trainer simulator, using various time compression (1.0X, 1.5X and 2.0X real-time). The pilots trained using ARRT performed better under emergency conditions and shot down 6 times more MIGs than those trained in real-time.

Report: "The Value of Simulation for Training"

Authors: Orlansky, J., C.J. Dahlman, C.P. Hammon, J. Metzko, H.L. Taylor and C. Youngblut

Organization: Institute for Defense Analysis

Publication Date: September 1994

Journal/Technical Report: IDA Paper P-2982

This is a landmark review of the training efficacy and cost analysis of simulators in the military. This paper represents a model for the present study, and provides an in-depth analysis from branches of the service, circa 1994. The purpose was to provide not only a review of the effectiveness of simulation in the military, but also to provide guidelines for the development of new instructional technologies that might prove useful for advanced distributed simulation. Unfortunately, despite the promise of Distributed Interactive Simulation (DIS) and related efforts in the military, these technologies did not reach fruition as quickly as was imagined by the authors of this report.

Four types of simulator were analyzed: (1) Stand-alone simulators, (2) Networked virtual simulation, (3) Live simulation and (4) Computer-based combat models (called 'constructive simulation' by the authors). These were examined in the context of individual and team training, in schools and in operating units.

(a) Review of budgets related to simulation and training

The authors present budgetary information on training and simulation in the military, how much it costs, who is trained and where it occurs. The information is drawn from a wide variety of sources, including DSMO, DARPA, logistics and manpower reports, and even commercial 3rd party suppliers of market research such as Frost & Sullivan. On many topics, the authors found it difficult to collect meaningful and/or reliable data.

The report presents a very rough estimate of costs of procuring simulators in the military in 1994, which amounted to:

Type of Simulator	Estimated Cost	Per Cent
Flight simulation	$0.8 billion	73%
Non-system devices	$0.243	22%
All other simulators	$0.057	5%
TOTAL	$1.1 billion	100%

Not included in these costs was maintenance of simulators, which was subsumed in the OPTEMPO budget and proved difficult to estimate. Total expenditures for research and development in training & education, including simulation, were $400 million for training and simulation equipment, $40 million for training methods and "modeling and

simulation" costs of about $190 million per year for DMSO, DARPA and the Joint commands.

(b) Training efficacy of simulation in the military

The general findings are similar to those found in the current analysis:

- When students are tested on actual equipment or in real-world procedures, training on simulators is as effective as training in real-world settings.
- The costs of using a simulator for training are always less than real-world training (ranging from 8 to 50%, depending upon equipment that is being used).
- Acquisition and life cycle costs are about half that of using actual equipment.
- The use of simulators for training does not mean that training using actual equipment should not also be used. In fact, the combination of simulation and real-world experience probably provide the best training (hybrid training technologies).
- The paradigm used to select simulators for training, rather than the actual equipment, should be: "Equal effectiveness at less cost".

(c) Service experience with simulation

In this section, the authors tried to identify "successful", "problematic" or "undetermined" experience with specific simulators and simulation training programs, elicited from each branch of the Service. The goal was to identify factors that may contribute to effective application of simulation in each of the Services.

The following examples, selected from a longer list provided by the authors, have been included here because they have features critical to the success of simulation-based training, and are felt to provide a foundation for the development of medical simulation in the military.

Army

Successful simulators:

Conduct of Fire Trainer (COFT) – The design process emphasized the identification of tasks, conditions and standards determined to be critical to crew proficiency. Success was considered to result from the development of a training program that integrated simulator usage.

National Training Center (NTC) and other Combat Training Centers (CTC) – Success was due to implementation of accurate performance metrics to improve simulator effectiveness.

Problematic simulators:

Improved Tank Training Ammunition – Problems resulted from a mis-match between simulation technology and the real-world thermal and light blooming effects, causing problems with tracking performance in the simulator.
Army Fighting Tank Vehicles – Problems because users did not adopt new fire tables developed for simulator – new tables were not established properly or supported as mandatory by senior personnel.

These reports identify some useful guidelines:

- High user acceptance is important for simulator effectiveness. Senior personnel must support simulator use and identify it as mandatory. Simulators must be integrated into a training program to be successful.

- Accurate performance measures are critical to simulator effectiveness.

Navy

There were a myriad of systems reviewed by the authors. These included primarily flight simulation trainers, as well as other systems such as warfare gaming systems. In general, helicopter simulators were considered the most useful training instruments and combat strategy systems were considered the least useful training systems, probably because they are primarily used for strategic coordination and not for training individual skill. The following observations were made in the study, based on feedback on simulator success provided by Navy personnel:

Reasons for success:

- High user acceptance was important for success in all cases.
- Performance feedback was important for success in all cases.

- The ability to train at the "margins", including emergency procedures under conditions where real-world procedural training would not be possible.
- Valuable for training where no acceptable alternative is available.
- Cost savings were important determinants for some simulation trainers.
- Fidelity was important for some trainers, because users needed acceptable levels of fidelity for realistic training experience.

Reasons for problems:

- Limited performance tracking and retrieval for feedback.
- Limited mission rehearsal capability.

- Lack of proper real-world fidelity, such as jamming, ground threats, other aircraft or submarines.

- Simulator was too expensive and not portable.
- Lack of encrypted links to other simulation platforms – simulators not well integrated with each other.

Marines

In 1994, approximately 90% of Marine simulators were used for flight training. Again, just a few simulators have been selected here to emphasize issues considered important for medical simulation. Other simulators were considered successful because of other factors such as cost effectiveness and acceptable levels of fidelity.

Examples of successful simulators:

- Remote Target System (RETS): Supports training in skills previously only trainable in actual combat or in infrequent force-on-force, free play exercises.

- Marine Corps Tank Full-Crew Interactive Simulation Trainer (MCTFIST) – Simulator saved training time and was cited as important for training of personnel prior to Desert Storm.

- Operational Flight Trainers (OFT), Weapon System Trainers (WST) and Weapons Tactics Trainers (WTT) – These have been well integrated as a requirement of flight training, and this is considered an important reason for simulator success.

Reasons for success:

- Strong user acceptance
- Simulators are integrated into training program.
- Portability was considered to be very important in some cases, allowing users to be trained during deployment and/or embarked aboard ship.

Air Force

In the Air Force, simulators are often used to complement flying time instead of substituting for flight time. Opportunistic approaches include adaptation of commercial training where appropriate. In 1994, emphasis was placed on system-wide review, including development of system training plans and phasing out of careers in aircrew/missile training devices.

Major deficiencies in existing simulators include decisions not to upgrade current equipment and not to provide certain capabilities such as improved graphics, motion bases, additional units or other capabilities.

Report: "Relationships Between Platoon Gunnery and Live-Fire Performance"

Authors: Sterling, B.S.

Organization: U.S. Army Research Institute for the Behavioral and Social Sciences

Publication Date: September 1996

Journal/Technical Report: NTIS ADA319342

This research examines the effect of training on platoon gunnery training (PGT) simulators on live fire performance for U.S. Army tank and Bradley Fighting Vehicle (BFV) platoons. In most cases, a positive correlation was found between performance in the PGT simulator and actual live fire performance (percentage targets hit in Tank Table XII scores) for both tank and BFV performance.

One of the most important findings of this study was the need to develop a training library database, containing different training cases and data from previous and current PGT simulator and live fire performance.

Report: "Transfer of Training Effectiveness of Personal Computer-based Aviation Training Devices"

Authors: Taylor, H.L., G. Lintern, C.L. Hulin, D. Talleur, T. Emanuel and S. Philips.

Organization: Institute of Aviation, University of Illinois at Urbana-Champagne

Publication Date: May 1997

Journal/Technical Report: DOT/FAA/AM-97/11

The authors investigated the use of personal computer-based aviation training devices (PCATDs) for training in flights skills. This has been a large area of interest in the flight simulation community, because PCATDs offer inexpensive (<$10,000) alternatives to the traditionally expensive and cumbersome flight simulation training devices.

The authors used the approach proposed by Williams and Blanchard (1995) who used task analysis as the basis for predicting transfer effectiveness. Using this approach, the appropriate task analysis is used to identify the learning requirements for a specific flight task, and these requirements would be organized based on common features shared between the requirements. The PCATD would then be evaluated to determine which of the learning requirements could be supported.

The authors tested 144 subjects in a transfer-of-training experimental design. Students were split into the experimental group, who trained on the PCATD, and the control group, who received similar training in an aircraft. Then both groups were examined on performance in actual flight criteria. The results showed that PCATD training led to savings in airplane flight, ranging from 15% to 40% depending on the training exercise. There were also cases where no savings were realized or produced negative results.

Report: "Simulator Design and Instructional Features for Carrier Landing: A Field Transfer Study"

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This is a transfer-of-training study examined different variables in visual simulation and their transfer to Field Carrier Landing Practice (FCLP). These variables are shown in the following Table (adapted from Westra et al, 1988):

Factors		Levels	
Field of View (FOV)	-27 to +9°		-30 to 50°
Vertical	± 24°		± 80°
Horizontal	Night point light		
Number of Trials	20	40	60
Approach Type	Segmented	Modified straight-run	All circling approaches

(a) Experimental Approach

Seventy-two experimental subjects (trained in the Visual Technology Research Center (VTRS)) and eight control subjects (no simulation training) participated in this analysis. Experimental subjects were trained in 20, 40 or 60 trials in the VTRS simulator, and then their performance was tested in actual landings.
Two kinds of questions were addressed in this study: (1) Can simulation training of carrier landing enhance performance in real world performance of actual landings as indicated by transfer-of-training analysis?, (2) Does simulator fidelity (scene detail and FOV) enhance trained performance? and (3) Do other variables such as approach type and number of trials affects performance?

The variables studied in this experiment included:

- Scene detail fidelity (day versus night)
- Field of view (wide versus narrow)

- Approach (segmented, modified straight-in, circling)
- Number of simulator trials (20, 40, 60)

(b) Transfer Results

Supplemental training on the VTRS enhanced actual, real-world performance on Glideslope performance and Lineup control in FCLP. Selected results, obtained using Analysis of Variance (ANOVA), are shown here (adapted from Westra et al, 1988):

Comparison	Df	Sums of square (%)	F
Glideslope Variability (Flights 3 and 4)			
VTRS versus Control	1	17.67 (4.0)	4.4*
Lineup Variability (Flights 3 through 8)			
VTRS versus Control	1	0.168 (4.5)	4.5*

*$p \leq 0.05$

Additionally, there were no recycles among the VTRS-trained pilots, but 7.9% of the control groups were recycled.

No effect on performance was related to increases in scene detail realized by day versus night simulation, or due to increases in the FOV from narrow to wide. Pilots who had 40 or 60 trials in the simulator scored better than those with only 20 trials. Since no significant differences were found between the 40 and 60 trial groups, it was suggested that pilots receive 40 trials to optimize training time. Similarly, since the segmented approach proved the most successful training scheme and involved the least amount of simulator time, it was suggested that this approach be used for simulation training.

(c) Analysis

This study shows that training using a carrier landing simulator increases subsequent performance in actual, world performance of Field Carrier Landing Practice, for glideslope control and lineup. Interestingly, increases in visual fidelity had no significant effect on actual performance, suggesting that in this case, for this simulator, lower fidelity simulator training was as effective as higher fidelity training.

D. Literature Database

The following is a list of references that was used in the current study. These publications focus on transfer from simulation to real world procedures, assessment of individual performance in the simulation environment, requirements for fidelity in simulation, and the use of part-task simulation trainers. In general, these papers include studies of military simulators, civilian flight simulators, but do not include studies limited to distributed simulation or unit training, and medical simulation papers and other references that are addressed and listed elsewhere in this report.

This is not an absolutely exhaustive list of all relevant publications. In some cases, papers were omitted because they represented duplicate findings of publications represented in the database, did not directly address issues pertinent to the present analysis, did not contribute significant data, or could not be easily obtained through sources such as the Defense Technical Information Service or related reference sources. In a few cases, references have been listed for completeness when they were quoted or referenced through other publications.

Publications are listed in alphabetical order, and are labeled according to the topics, which are discussed, including an indication of which publications constituted a meta-analysis of the literature. Labels are indicated when a given publication contains a substantial amount of information to a given topic.

General topic labels:

M: Meta-analysis – These publications are reviews, meta-analyses or consensus reports summarizing an area of research in simulation.

T: Transfer-of-training – The most frequent publication examined in the current study, these papers examine training efficacy of individual simulators or review training studies, including transfer from the simulator to real-world procedures. In most cases, these studies provide examples and recommendations on how specific simulator features contribute to, or detract from, training efficacy.

P: Performance Assessment – These publications address some aspect of performance assessment that is embedded within the simulator, usually performance tracking functions built into the computer.

F: Fidelity – These studies look at physical or functional characteristics of simulator fidelity, and how important simulator fidelity is for training efficacy. Almost all of these studies have shown that physical fidelity is not important for training efficacy.

PT: Part Task Training – There is a large literature on the relative benefits of part task versus whole task training. These studies examine the benefits of part task trainers for applications such as procedural training.

Topic					Publication
				PT	Adams, J.A. and L.E. Hufford (1962) Contributions of a part-task trainer to the learning and relearning of a time-share flight maneuver. Human Factors 4:159-270.*
M	T		F	PT	Advisory Group for Aerospace Research and Development, NATO (1980) Fidelity of Simulation for Pilot Training, DTIC ADA096825.
	T				Angier, B.N., E.A. Alluisi and S.A. Horowitz (1992) Simulation and Enhanced Training. Institute for Defense Analysis, Alexandria, VA, IDA Paper P-2672
	T			PT	Aukes, L.E. and G.G. Simon (1957) The relative effectiveness of an air force training device used intact versus with isolated parts. AFPTRC Technical Note Number 57-77, AD131429.
	T			PT	Bailey, J., R.G. Hughes and W.E. Jones (1980) Application of backward chaining to air-to-surface weapons delivery training. Flying Training Division, Air Force Human Resources Laboratory. AFHRL TR-79-63, ADA085610.
	T	P	F		Benton, C.J., P. Corriveau, J.M. Koonce and W,C. Yire (1992) Development of the basic flight instruction tutoring system (BFITS). Air Force Systems Command. AL-TP-1991-0060.*
			F		Boldovici, J.A. (1987) Simulator motion. Army Research Institute. TR961 ADA257683.
	T				Brictson, C.A. and W.J. Burger (1976) Transfer of training effectiveness: A7E night carrier landing trainer (NCLT), device 2F103. Dunlap and Associates. N61339-77-D-0028.*
	T				Brictson, C.A. and S. Breidenbach (1981) A7E training effectiveness evaluation: The use of the night carrier landing trainer (NCLT) device 2F103. Naval Training and Equipment Center, NAVTRAEQUIPCEN74-C-0079-1.*
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	T				Browning, R., L. Ryan, P. Scott and A. Smode (1977) Training effectiveness evaluation of device 2F87F p-3C operational flight trainer. Training Analysis and Evaluation Group,. TAEG Report No. 42.*

	T				Browning, R., L. Ryan and P. Scott (1978) Utilization of device F87F OFT to achieve flight hour reductions in P-3 flight replacement pilot training. Training Analysis and Evaluation Group,. TAEG Report No. 54.*
	T				Browning, R., L. Ryan and P. Scott (1978) Utilization of device F87F OFT to achieve flight hour reductions in P-3 flight replacement pilot training. Training Analysis and Evaluation Group,. TAEG Report No. 54.*
	T				Browning, R., W. McDaniel, P. Scott and A. Smode (1982) An assessment of device 2F64C for training helicopter replacement pilots. Training Analysis and Evaluation Group. U.S. Navy Technical Report 127.*
	T				Burger, W. and C. Brictson (1976) A7E transfer of training effectiveness: Device 2C15A and device 2F84B OFT/WST. Naval Training and Equipment Center, NAVTRAEQUIPCEN74-C-0079-2.*
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	T	P			Caro, P. and R. Isley (1966) Helicopter trainee performance following synthetic flight training. Proc. Southwestern Psychological Association.*
	T				Caro, P., R. Isley and O. Jolley (1973) Research on synthetic training: Device evaluation and training program development. HumRRO Division No. 6. U.S. Army Research Institute for the Behavioral and Social Sciences.
	T				Caro, P., R. Isley and O. Jolley (1975) Mission suitability testing of an aircraft simulator. HumRRO-TR-75-12. U.S. Army Research Institute for the Behavioral and Social Sciences.
	T	P			Caro, P., W. Corley, W. Spears and A. Blaiwes (1984) Training effectiveness evaluation and utilization demonstration of a low-cost cockpit procedures trainer. Naval Training and Equipment Center, NAVTRAEQUIPCEN78-C-0113-3.*
M	T		F		Carretta, T.R. and R.D. Dunlap (1998) Transfer of Effectiveness in Flight Simulation: 1986 to 1997. U.S. Air Force Research Laboratory, NTIS ADA362818.*

		P			Connolly, T.J., B.B. Blackwell and L.F. Lester (1989) A simulator-based approach to training in aeronautical decision making. Aviation, Space and Environmental Medicine 60:50-52.
	T	P	F		Copenhaver, M.M., H.L.F. Ching and L.G. Pierce (1996) Training Effectiveness Evaluation of an MLRS Fire Control Panel Trainer Using Distributed Interactive Simulation. Army Research Laboratory, NTIS ADA307678.*
	T				Crosby, J.V. (1977) Cognitive pretraining: An aid in the transition from instrument to composite flying. Flying Training Division, Air Force Human Resources Laboratory. AFHRLTR-77-62, ADA48816.
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	T				Cicchinelli, L. K. Harmon, R. Keller and J. Kottenstette (1980) Relative cost and training effectiveness of the 6883 three-dimensional simulator and actual equipment. Logistics and Technical Training Division. AFHRL-TR-80-24.*
	T				Cicchinelli, L. K. Harmon and R. Keller (1982) Relative cost and training effectiveness of the 6883 F-111 converter flight control systems simulators as compared to actual equipment. Air Force Human Resources Laboratory. AFHRL-TR-82-30.*
	T				Cicchineli, L. and K. Harmon (1984) Training and cost effectiveness of two avionics maintenance training simulators. Air Force Human Resources Laboratory. F33615-78-C0018.*
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M	T		F		Hays, R.T. and M.J. Singer (1989) Simulation fidelity in training system design. New York. Springer Verlag.
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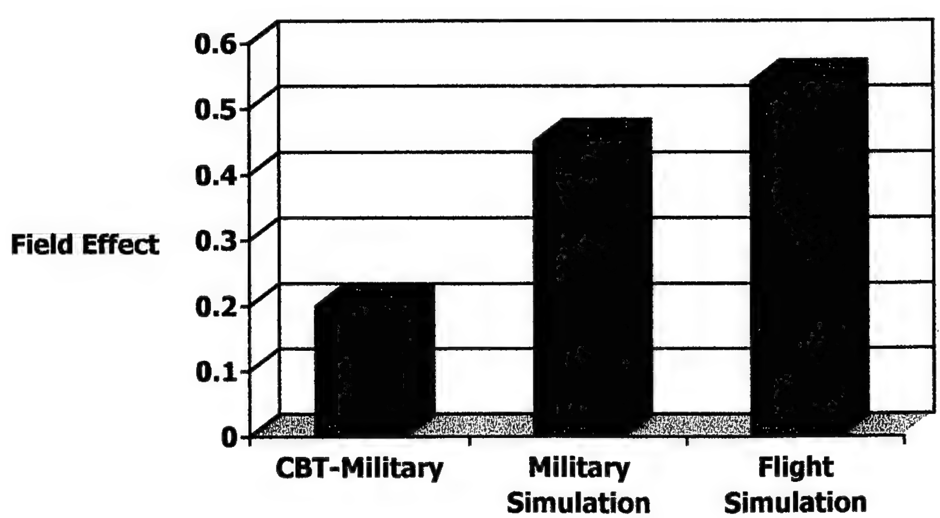
E. Quantitative Measure of Field Effect

Glass (1997), Hays et al (1992), Johnston (1995) and others have provided the context and technical approaches used for determining field effects in the instructional literature using a meta-analytic approach. Field effect is usually defined as the difference between the means of two groups divided by the standard deviation of the control group. Effect sizes determined in this way estimate the difference between two group means measured in control group standard deviations. Johnston calculated field effects for a variety of instructional design studies. The effect sizes for computer-based training range from 0.20 to 0.46 depending on the population. The effect size for flight simulation, based on the work of Hays et al (1992) was 0.54, producing one of the strongest positive field effects of the instructional technologies that were studied.

Our preliminary results, which are in the process of being written up as an original research article, are based on an analysis of the literature on flight simulators and other simulators used in the military. Studies included in the present analysis are identified by an asterisk in Section D, Literature Database. We have used an approach similar to that suggested by Glass (1997), but with some modifications using a general variance-based method as outlined in Petitt (2000).

The preliminary results are presented in Figure #4. These findings suggest that simulation-based training in the military is an extremely effective method of instruction, with a Field Effect of 0.44.

Figure #4: Quantitative Estimate of Training Effect: Military Simulation



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III. Current Status and Future Trends: Simulation in the U.S. Military

The military simulation experience provides guidance for the development of medical simulation, based on the analysis of past and current efforts. Of equal importance are budgetary, programmatic and technology trends in the broader military simulation community that will impact future development of medical simulation in the military and civilian sectors. This chapter reports on current budgets, programs and simulators to frame the discussion on the development of medical simulation. Trends are identified that can be leveraged for successful implementation of simulation in the medical domain.

A. Current Programs and Budgets for Simulation and Training

1. Total Budgets

The military invests heavily in simulation and training. In many cases, it is difficult to separate investment in simulation from investments in related budget items such as training programs, technology development and infrastructure. However, general estimates can be made based on data collected from all Service branches, other DoD programs, private market analysis and published information.

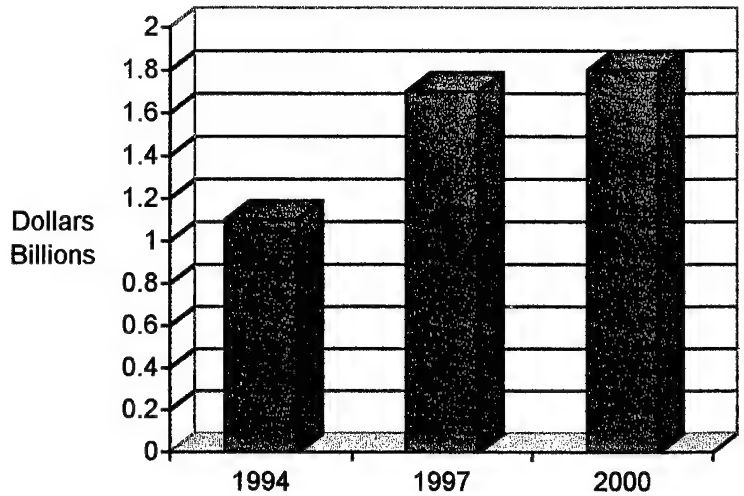
Our estimate of the current total size of the U.S. military simulation and training investment is approximately $1.8 billion per year, including RDT&E (research and development, testing and evaluation), procurement and services (Figure #5). This figure is based on information from a variety of sources, which may or may not factor in costs related to support such as ongoing maintenance of simulators, and does not include the military's minor investment in medical simulators such as patient mannequins or virtual reality systems in medicine. This amount compares to estimates of $1.1 billion in 1994 and $1.7 billion in 1997 (Figure #5).

Additional money is spent on maintaining simulators and other training expenses, including operational expenditures. In 1994, Orlansky estimated this figure to be somewhere in the range of $9 to $20 billion in 1994.

2. Total Budget Forecast and Segmentation into Components

Figure #6 shows the forecast and breakdown of total U.S. military investment in simulation. Although some fluctuation in budgets is apparent over the next 5 years, there is expected to be a compound annual growth rate estimated to be in the range of 2-3% over the next 5 years. Procurement of new simulators is the largest budgetary component, followed by research and evaluation (RDT&E) and training services.

Figure #5. Estimated Size of Total U.S. Military Investment in Simulation in 2000, including RDT&E, Procurement and Services



1994: From Orlansky et al (1994). Orlansky et al (1994) made an estimate on based on military sources and third party market research studies (Frost & Sullivan). We have followed their lead, and derived data based on a number of traditional and innovative sources of information. 1997, 2000: Data derived from Frost & Sullivan.

Figure #6: Forecast Estimate and Segmentation of Simulation Budget, Total U.S. Military, 2000-2005

Year	RDT&E	Procurement	Services	Total	% Change
2000	$644 M	$707 M	$454 M	$1,804 M	-
2001	683	729	480	1,892	4.8
2002	672	726	485	1,883	-0.5
2003	727	762	517	2,006	6.5
2004	714	727	514	1,955	-2.6
2005	741	755	547	2,043	4.5

Data from Frost & Sullivan

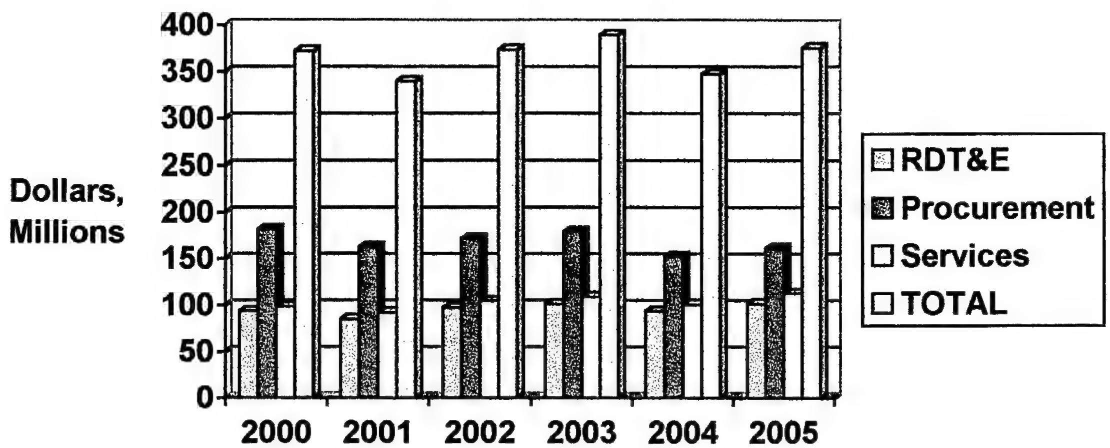
3. Programs and Budgets by Service and Department of Defense

(A) Army

1) Budget

The current budget, components and forecasts for U.S. Army simulation and training are shown in Figure #7.

Figure #7: Forecast Estimate and Segmentation of Simulation Budget, U.S. Army, 2000-2005



2) U.S. Army Programs

(a) Management

STRICOM is the primary army management organization responsible for simulation and training. In 1999, STRICOM managed $833 million for the U.S. Army. STRICOM is:

- The technology base for training and testing simulators, simulations and simulation instrumentation for the U.S. Army
- DoD Technical Manager and DoD Executive Agent for Advanced Distributed Simulation (ADS)
- DoD Executive Agent for Aggregate Level Simulation Protocol (ALSP)
- Executive Agent for Combat Training Centers Instrumentation
- Acquisition management of:
  - Man-in-the-loop simulation support for early user requirements and materiel concept requirements
  - Live, virtual and constructive simulations, simulators and training systems
  - Technical and operational test instrumentation
  - Targets and threat simulator support

- "Life Cycle" Sustainment and Post Deployment Software Support (PDSS) for Fielded Army Training Systems and Simulators

The Four Project Managers (PMs) of STRICOM are:

- PM Combined Arms Tactical Trainer (PM CATT): PM CATT manages the development, acquisition, fielding, and life cycle support of combined arm training systems and training aids, devices, simulators, and simulations (TADSS) to support individual, institutional, and collective training. The mission excludes training systems and instrumentation in support of live, combat training center, and force-on-force engagement training and threat-specific simulation systems, which are managed by other STRICOM Project Managers. CATT is a group of fully interactive networked simulators and command, control, and communications work stations, replicating the vehicles and weapons systems of a company/team and its supporting combat, combat support, and combat service support elements, operating on a simulated real-time battlefield:
  - Develop and field networked simulators for training collective battlefield tasks.
  - Develop and field commander and staff "war game" simulations.

- PM WARSIM: PM WARSIM is responsible for the life cycle management of command and control battle simulations to train commanders and their staff in the art of war from company level to echelons above Corps. The simulations are used by the Army to satisfy, in part, its Title X (training) responsibility, including the Corps Battle Simulation (CBS), the Tactical Intelligence Simulation (TACSIM), and the Synthetic Theater of War (Army) (STOW-A). The Aggregated Level Simulation Protocol (ALSP) is used to link constructive simulations to create the battlefield environment required to support the training.

- PM Instrumentation Targets and Threats Simulators (ITTS): PM ITTS manages the research, development, design, acquisition, fielding, modification, and capability accounting of major instrumentation, targets, and threat simulators required for developmental and operational test and evaluation (T&E) and training. It manages the Central Test and Evaluation Investment Program (CTEIP) and Resource Enhancement Program (REP) for the Army. It manages operations of targets for T&E and training of Army and Foreign Military Sales (FMS) customer troops. Manage the Army Instrumentation, Targets, and Threat Simulators (ITTS) Long Range Planning Process. It develops and implements policy direction and control over funding and execution of major instrumentation, targets and threat simulator/simulation projects, and serves as the Army's single manager for acquiring targets, threat simulators/simulations, and major test instrumentation. Major PM ITTS initiatives include:
  - Provide discipline to the acquisition of instrumentation, targets, and threat simulators
  - Serve on Validation and Threat Accreditation Working Groups for targets and threat simulators

- Manage foreign materiel required to support developmental and operational test and evaluation not managed by the U.S. Army Operation, Test and Evaluation Command (OPTEC) Operational Threat Support Activity (OTSA)
- Execute the Long Range Planning System (LRPS) and other databases for ITTS
- Support the Tri-Service T&E Reliance Process
- Support the technology transfer for the integration of Testing and Training
- Support integration of High Level Architecture (HLA) with T&E

➢ PM Training Devices (PMTRADE): PM TRADE is responsible for managing the acquisition of affordable training systems that meet the user's requirements, delivered on schedule, within cost, and to life-cycle manage these best value products for the Army and/or Joint Service customer(s). Responsibilities include (1) serving as the AMC Executive Agent for Maneuver Combat Training Center Instrumentation and System Acquisition (2) Management of the development, acquisition and fielding of live training instrumentation systems, non-system individual and crew type training Aides, Devices, Simulations, Simulators (TADSS), Tactical Engagement Simulators (TES) and generic training threat simulators which are: associated with the Combat Training Centers, Homestation and MOUT facilities; for use in the live environment and force-on-force training; associated with Foreign Military Sales; in support of System PM's and other customers as assigned; and in support of training the digitized force in the live environment (3) Support to institutional learning/training and (4) Digitization in the live environment. PM TRADE leads, manages, supervises, coordinates and integrates the efforts of two board selected Product Managers (PMs), and an Assistant Project Manager (APM) responsible for Digitized Training.

(b) Selected Army Simulation Programs and Projects

This section describes selected U.S. Army programs that may be of interest to developers of medical simulation systems. This is not an exhaustive list of simulation programs and projects, but rather selected examples that highlight current efforts to develop simulators and simulation systems in the broader military community. These have been selected because they feature technology development and trends that may be useful for medical applications (eg, image generation, distributed interactive simulation), human factors studies whose results may apply to medical simulation, simulators that focus on procedural or skills training and development, and exemplars such as the use of simulation in Combat Training Centers (CTC) that provide a guide for medical simulation development efforts. Emphasis is placed on non-system training, and includes areas such as distributed interactive simulation, image generation, visualization and virtual environment technologies, human factors and performance training, and non-system training device development.

i. Distributed Interactive Simulations (DIS) Research

Although DIS research and development is "distributed" across several programs and projects in the Army, several efforts have been described together here to illustrate the status, scope and nature of future initiatives in this area. Please note that additional information on related efforts such as Advanced Distributed Learning (ADL) are described elsewhere in this report.

PE 0604760A Distributed Interactive Simulations – Engineering Development

DIS is a synthetic environment in which humans may interact through a network of connected simulators, including different subcomponent simulations and instrumented live task forces. These components may be located at the same place or at geographically dispersed locations, yet can interoperate using a variety of simulator hardware linked through use of standard communication architecture. By creating environments, which allow various types of interactive simulators to communicate, effective training can be accomplished at a variety of levels, from operational team training to force-on-force combined arms training.

This PE supports the Army's Advanced Simulation Program to enable readiness and support the development of concepts and systems for Force XXI and the 'Army After Next' through the application of new simulation technology and techniques. This engineering development and application of simulation technology will provide tools to electronically link all subcomponents together in a manner that is transparent to the user. For example, In order for DIS to take advantage of currently installed and future simulations manufactured by different organizations, a means must be found for assuring interoperability among dissimilar simulations. One step in achieving this interoperabiltiy has been to develop a communications protocol. There must be an agreed-upon set of messages that allow host computers to communicate information about the vehicles or entities that they represent in the simulated world and allow them to interact.

The synthetic environment is used to verify the scenarios, tactics/techniques and procedures, train testers on new hardware and software, and conduct trial test runs before costly live field tests. The tools developed are available for use and reuse by all users in the Army.

The project components include:

- Project #DC73 Synthetic Theater of War (STOW): This project supports engineering and integration of high fidelity and distributed simulation capability to support large, scale joint venture operations and analysis.

- Project #DC77: Interactive Simulation: This project developed DIS technologies such as HLA (High Level Architecture) for wide area simulation networking in support of modeling and simulation, doctrinal development, training, and operations, using live, virtual and constructive simulations.

- Project #DC78: Computer Generated Forces: This project is focused on the development of simulated units and forces.

PE 0602308A Advanced Concepts and Simulations

This PE focuses on the development of modeling and simulation capabilities for entities such as the U.S. Army Training and Doctrine Command (TRADOC) Battle Labs, Force XXI and Army After Next. Its goal is the creation and validation of a synthetic electronic battlefield environment, including development of tactics, training techniques, soldier support, systems and system upgrades. Projects include Advanced Distributed Simulation and Advanced Concepts and Technology.

Project #AC90, Advanced Distributed Simulation – This project developed enabling technologies for advancing DIS in the synthetic environment and battlefield representation to support use of modeling and simulation as an acquisition tool and training. The Battlefield Distributed Simulation – Developmental (BDS-D) program provides a virtual environment in which lethal combined arms will involve the warfighter in the loop for testing new systems concepts, tactics and doctrine and test requirements at a reduced cost and time than traditional approaches.

PE 0601104A University and Industry Research Centers

This program element is focused on the creation of three open, federated laboratories that partner the Army Research Laboratory (ARL) with external institutions in academia and private industry that can provide additional expertise and recognized competencies in specific technology areas not available in the Government.

Project #BH 53 Advanced Distributed Interactive Simulations Research - This project is a collaboration between the ARL and selected Army Center of Excellence in Information Sciences (ACEIS). Currently, Clark Atlanta University, a HBCU, performs work in information science, including interactive and intelligent systems, database and information systems and distributed and parallel processing systems.

ii. Image Generation, Visualization and Virtual Environments

PE 0602784A Military Engineering Technology

This is an applied research project that focuses on technology development for enhancing the function of the warfighter, including battlefield visualization, tactical decision aids, weather intelligence products and capabilities to exploit space assets. Among the numerous simulation projects supported by this PE is Topography, Image Intelligence and Space Technology, which is used here as an example of technology development that may be leveraged for use in the medical simulation arena.

Project #A855 Topography, Image Intelligence and Space Technology – This project is focused on the development of information, intelligence and visualization technologies to

support the tactical commander on the battlefield. Information dominance on the battlefield is emphasized, supporting the commander to locate and position enemy and friendly forces under all light and weather conditions, providing terrain data for command and control and modeling and simulation systems, and enhance the speed and accuracy of weapons and other systems. This project is managed by the U.S. Army Topographic Engineering Center.

PE 0603308A Army Missile Defense Systems

Project #D979 Tactical Simulation Interface Unit (TSIU) – This project develops is a workstation "black box" that links simulation environments and command and control systems by interfacing with simulations complaint with the IEEE standards on DIS. It will interface, process and route computer-generated simulations to appropriate C41 systems. Its goal is to provide simulations on tactical workstations for training of personnel in deployable settings.

PE 0604780A Combined Arms Tactical Trainer (CATT)

This is a family of combined arms simulation systems, including the initial Close Combat Tactical Trainer (CCTT). The CCTT provides the underlying baseline architecture, terrain visualization and databases, after action review, semi-automated forces and models and algorithms for development of the CATT family of simulators. These simulators will provide a realistic, interactive synthetic battlefield for skills training of crews and larger groups to use combined arms in a cost-effective fashion.

Project #D582 Synthetic Environment Core – The SE Core provides terrain databases, aviation behaviors, Air Defense models, natural effects that will enable Army aviation units to conduct collective training and aviation combined arms training in the virtual battlefield environment. These include development of semi-automated forces behaviors to represent the digitized battlefield, and development of scenarios for After Action Review.

iii. Human Factors and Performance

Defense Research Sciences: Project #B74F: Personnel Performance and Training

This project builds on the broader work of extramural and intramural programs of the Defense Research Sciences (PE 0601102A), including the Army Research Laboratory (ARL), Army Materiel Command Research (Development and Engineering and laboratories), the Army Corps of Engineers laboratories, the Army Research Institute and the Army Research Office (ARO). The Personnel Performance and Training project conducts behavioral science and human factors research for improvement of human performance and training, including:

- Methods for faster learning and improved skill retention
- Leader effectiveness for improved team performance
- Understanding the impact of societal trends on Army readiness
- Improving the match between soldier skills and their jobs to optimize performance

- Research on small team performance, leadership and training

PE 0602716A Human Factors Engineering Technology

This program element involves the collection of human performance data in laboratories and in the field, with emphasis on the capabilities and limitations of soldiers in the field, emphasizing interaction between the soldier and his equipment. Secondly, this program emphasizes the development, field testing, and empirical validation of methods for coordination of civilian and military emergency medical teams.

Project #AH70 Human Factors Engineering Systems Development – The goal of this project is to develop human factors data such as usability and ergonomics for the design of weapons systems and equipment standards, guidelines, handbooks and soldier training manpower and training requirements.

PE 0602785A Manpower/Personnel/ Training Technology

One focus of this program is to provide behavioral technologies required for the development of effective individual and unit training strategies including simulation-based synthetic environments. Relevant research topics include the development of strategies in simulated environments and the optimum design of simulators and training devices to provide maximum training at minimum cost.

iv. Simulation to Support Training in Combat Training Centers (CTC)

PE 0604715A Non-System Training Devices – Engineering Development

This program element funds engineering development of Non-System Training devices, which are not dedicated to support of a single item or weapon, but provide general military training and broader training using simulation technologies. The purpose is to maximize transfer of knowledge, skills and experiences from the training situation to the combat setting. Realistic devices are developed for force-on-force training at the National Training Center (NTC), Ft. Irwin, CA; Joint Readiness Training Center (JRTC), Ft. Polk, LA and Combat Maneuver Training Center (CMTC), Hohenfels, Germany, and battle staff training in the Battle Command Training Program (BCTP).

Project #D241 Non-System Training Devices Combined Arms – This project develops prototype devices to support Combined Arms training and multi-system training within the Army. Components include:

- WARSIM is the next generation battle simulation. It uses current technology to effectively provide training support and linkage to other simulators. WARSIM complies with the Simulation Interoperability Standards Organization (SISO) and High Level Architecture (HLA) compliance. WARSIM is the land component of the Joint Simulation System (JSMIS).

- Engagement Skills trainer (EST) provides individual and squad level home station training using a deployable smalls arms engagement trainer and includes the development of training devices, simulations and instrumentation for the Combat Training centers (CTC), Joint Readiness Training Center Military Operations in Urban Terrain (JRTC MOUT), and National Training Center Objective Instrumentation (NTC OIS) to provide a completely digital-based system for full tactical system connectivity and HLA compatibility.

- The Combat Synthetic Training Assessment Range (CSTAR) is battle command training system that provides large scale, brigade training at the National Training Center (NTC) and at Ft. Hood.

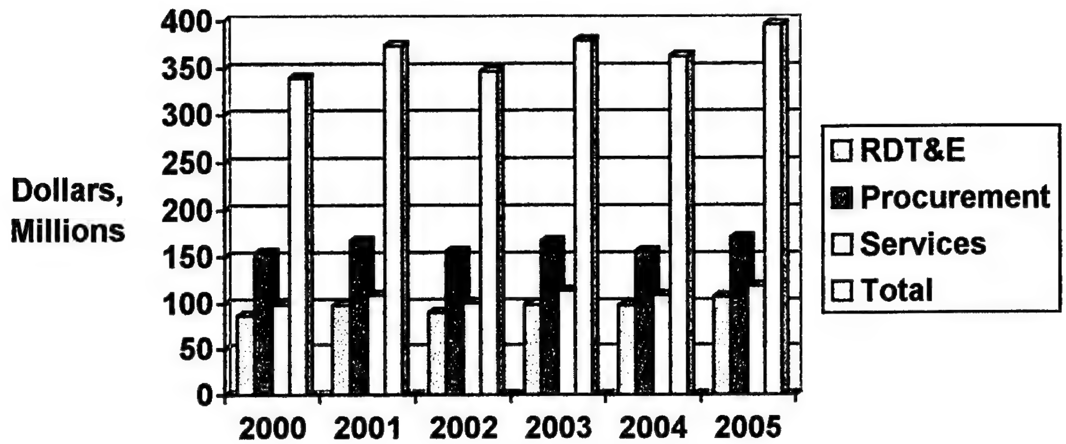
- The Intelligence Electronic Warfare Tactical Proficiency Trainer (IEWTPT) provides high fidelity battle command training by creating a realistic intelligence information environment for the Military Intelligence (MI) soldier.

(B) Navy

1) Budget

The current budget, components and forecasts for U.S. Navy simulation and training are shown in Figure #8.

Figure #8: Forecast Estimate and Segmentation of Simulation Budget, U.S. Navy, 2000-2005



2) Navy Programs

(a) Management

The Naval Air Systems Command operates the Naval Air Warfare Center – Training Systems Division (NAWC-TSD), which provides fully integrated life-cycle support for training systems using state-of-the-art simulation and training technologies for all Naval warfare areas and other services. Many of the following programs are managed by NAWC-TSD.

(b) Selected Navy Simulation Programs and Projects

This section describes selected U.S. Navy programs that may be of interest to developers of medical simulation systems. This is not an exhaustive list of simulation programs and projects, but rather selected examples that highlight current efforts to develop simulators and simulation systems in the broader military community. This group of program elements and projects has been selected because it provides examples of the extensive use of simulation in the Navy for training and mission planning and rehearsal, capabilities that need to be imported into the medical simulation domain. Emphasis is placed on broad initiatives focused on general use and non-system training devices, including skills training

and performance assessment not related to specific equipment, weapons systems or testing and evaluation, and on mission planning and execution.

PE 020044571N Consolidated Training Systems Development

This is program element provides a major source of support for the development of simulation-based training systems for the Navy. The following programs are included in this program:

- Project #21427 Surface Tactical Team Trainer (STTT) – The STTT will develop the Battle Force Tactical Training (BFTT) System to provide realistic joint warfare training including a means to link ships together for coordinated Combat System team training using Distributed Interactive Simulation (DIS) protocols.

- Project W0431 Tactical Aircrew Combat Training System (TACTS) – TACTS provides real-monitoring and post-exercise debrief of aircrews flying on instrumented training ranges. The system is the primary training tool used by the Naval Strike and Air Warfare Center and the Marine Aviation Weapons and Tactics Squadron.

- Project W0604 Training and Instrumentation Development (TRID) – The TRID program develops many range systems including range electronic warfare simulation, advanced weapons training systems, laser training systems, Large Area Tracking Range (LATR) and shallow water range technology.

- Project W1998 Joint Combat Tactical Training System (JTCTS) – JTCTS is planned to provide fleet deployable instrumentation at the sea surface, subsurface, and air training and tactics development and fixed/transportable air range instrumentation. JTCTS incorporates the Defense Modeling and Simulation Office (DMSO) – sponsored Distributed Interactive Simulation Protocol data unit for interoperability with Navy and other service live, virtual simulators and constructive (wargame) simulations.

- Project W2124 Air Warfare Training Development (AWTD) – The AWTD program developed many of the aviation training systems including mission rehearsal technologies and the Aviation Training Technology Integration facility (ATTIF).

- Project X1823 Training and Training Devices Systems (TTDS) – The TTDS provides a geographically dispersed wargaming system for littoral operations training that supports objectives of Fleet Commanders, the Naval War College, Joint Warfare Center, and Tactical Training Groups in wargaming, tactical decision-making training, and tactics development and evaluation.

- Project X1824 Training and Modeling Systems (TMS) – The TMS encompasses the requirements analysis and software development associated with the Navy's

Maritime Development Agent function as part of the Joint Simulation System (JSIMS).

PE 0206313 Marine Corps Communications Systems

Project #C2315 Training Devices / Simulators – Training simulators developed and supported by this project include the Joint Simulation Systems (JSIMS), Range Instrumentation Systems (RIS) and Combat Vehicle Appended Trainer (CVAT). These simulation systems train tactical and decision-making skills from entity level through Marine Air-Ground Task Force (MGTF) staff level. These systems are designed to be interoperable and provide for mission planning, mission rehearsal and concept evaluation in a valid synthetic environment with objective performance assessment. Through, virtual, constructive (wargaming) simulation, this will provide the Marine Corps with the ability to train jointly, educate, developed doctrines and tactics, formulate operational plans, assess warfighting situations and define operational; requirements.

PE 0308601 Modeling and Simulation Program

This new program element funds the efforts of the Navy Modeling and Simulation (M&S) Management Office and the Department of the Navy Technical Support Group (TSG). It supports technical and management initiatives directed by Congress, DoD and SECNAV with the aim of brining organization and focus to the development of M&S tools throughout Navy and DoD. Activities are organized into four areas:

- Engineering Studies and Analysis, to define the feasibility and applicability of proposed standards to Navy and to investigate service-unique requirements for standards or guidance.

- Products and Services, to define the policy, standards, and common tools and services necessary to guide more efficient development and use of M&S across the Navy. The goal is to reduce stovepiped development, promote tool reuse, support informed M&S investment decisions, develop, and manage the Navy M&S Information System (NMSIS).

- M&S Quality Assurance Program, to establish and manage a disciplined process of model verification, validation and accreditation (VV&A) required by current directives.

- Simulation Experiments, to test distributed simulation technology in fleet exercises, experiments, and pilot efforts that demonstrate and examine the value and limitations of proposed standards (eg, HLA and JMASS) to mission and program requirements.

PE 0603707 Manpower, Personnel and Training – Advanced Technology Development

This broad program element includes the support of training using simulated environments while deployed and the maintenance of complex weapons systems.

Project #R1772 Training Systems Development – This project improves mission effectiveness and safety by applying both simulation and instructional technology to the design of affordable education and training methods and systems. It developed and evaluates systems to improve basic through advanced individual and team training, skill maintenance, and mission rehearsal capabilities. It improves efficiency and cost-effectiveness by applying operations research, modeling and simulation, and instructional, cognitive and computer sciences to the logistics, development, delivery, evaluation and execution of training. This project also incorporates the Virtual Environment/Training Research project, which was consolidated in 2000.

PE 0604231 N: Tactical Command System

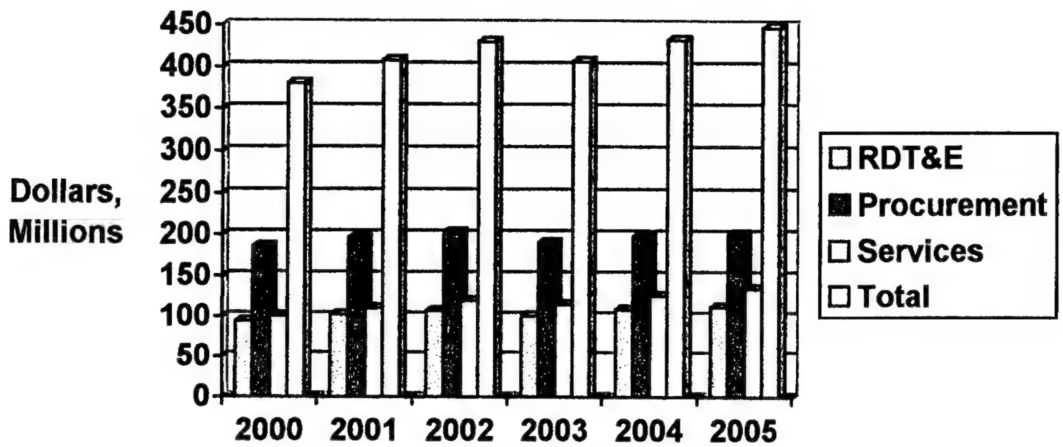
Project #X2306 Naval Simulation System (NSS) – The NSS provides a capability to simulate the execution of Naval warfare and Operations Other Than War. This project provides Fleet Commander centers, both ashore and afloat, with the capability for course of action assessment, evaluating the effectiveness of operational planes with measures defined by the fleet planner.

(C) Air Force

1) Budget

The current budget, components and forecasts for U.S. Air Force simulation and training are shown in Figure #9.

Figure #9: Forecast Estimate and Segmentation of Simulation Budget, U.S. Air Force, 2000-2005



2) Air Force Programs

(a) Management

In the Air Force, management of simulation and training programs is spread over many different agencies. Two key agencies are the Aeronautical Systems Center (ASC), including the Training Systems Product Group (TSPG) at Wright-Patterson Air Force base near Dayton, OH and the Air Force Agency for Modeling and Simulation (AFAMS) in Orlando, FL.

<u>Aeronautical Systems Center (ASC), Training Systems Product Group (TSPG)</u>

The TSPG is responsible for research, development, acquisition and maintenance of training systems. The TSPG is responsible for the Distributed Mission Training (DMT) programs, which focuses on training aircrew members in the content of the Joint Synthetic Battlespace outlined in Joint Vision 2010. Programs of the TSPG include:

- Air Combat Programs
  - F-16 Aircrew and Maintenance systems
  - Surveillance Radar Set (SRTS)
  - Joint STARS Flight Crew Training Systems

- Bomber Systems Training Branch
    - B-1B Training System

- Air Force Reserves Program
    - C-130 Training Systems Branch

- Air Mobility Command Branch
    - C-17 Training System
    - C-141 Aircrew Training System

- Foreign Military Sales

Air Force Agency for Modeling and Simulation (AFAMS)

The AFAMS is a newly created field operating agency whose main objective is to coordinate the Air Force's growing requirements for modeling and simulation. The agency's mission is to support implementation and use of the Joint Synthetic Battlespace by: implementing USAF/DoD modeling and simulation (M&S) policy and standards, managing, coordinating and integrating major USAF M&S programs and initiatives, and promoting and supporting simulation technology improvements.

(b) Selected Air Force Simulation Programs and Projects

This section describes selected U.S. Air Force programs that may be of interest to developers of medical simulation systems. This is not an exhaustive list of simulation programs and projects, but rather selected examples that highlight current efforts to develop simulators and simulation systems in the broader military community. This group of program elements and projects has been selected because it provides examples of the extensive use of simulation in the Air Force for flight training, mission planning and rehearsal, which are capabilities that need to be imported into the medical simulation domain. Additional information is provided on flight simulation and aircraft simulators.

PE 0207601F USAF Modeling and Simulation

This program element provides RDT&E for major USAF modeling and simulation efforts including the National Air and Space Warfare Model (NASM), which is the air and space element of the Joint Simulation System (JSIMS), the Joint Modeling and Simulation System (JMASS) and manpower authorizations for JSIMS. JSIMS will be the sole readiness training simulation used for training joint force commanders, joint task force tasks, components and their staffs, including joint force air component commanders and Air Operations Center personnel. JMASS provides High Level Architecture (HLA) – compliant architecture for aggregate level simulations.

Project #1008 National Air and Space Model (NASM) – The NASM project is a new wargaming model that supports battlestaff training, education and military operations including mission rehearsal, and acquisition decisions. NASM includes an overall USAF

M&S architecture and provides a reusable, portable, scaleable and robust distributed simulation core for other simulations. NAMS includes a combat resolution model to meet the needs of USAF Major Commands (MAJCOMs) and unified/specified command air components to train air component commanders and their battle staffs.

Project #4567 Joint Modeling & Simulation System (JMASS) - JMASS is a simulation support environment for the development, configuration, execution and analysis of high fidelity, repeatable simulations with re-usable models – focus is on tactical/engagement level simulations with a concentration on electronic combat. JMASS is a full system software implementation of modern object-oriented and object-based simulation architecture. JMASS provides users with the software tools and applications to develop objects, assemble these objects into models, configure the models in a complete simulation, execute the simulation, and post-process the simulation data.

Project #4582 Aeronautical System Center's Simulation and Analysis facility (SIMAF) – SIMAF supports the Joint Synthetic Battlespace, and focuses on the integration of existing and emerging modeling, simulation and analysis capabilities.

<u>PE 0207605F Wargaming and Simulation Centers</u>

The Theater Air Command & Control Facility's (TACCSF) mission is to provide advanced distributed simulation to the warfighter for improving theater air and space warfare systems and concepts of operations. This facility will be available to users who require a high fidelity battle management, command, control, communications, computer and intelligence simulation. TACCSF performs the upgrade to a complex system of 23 Air Force and Army weapons systems simulators (containing over 2 million lines of software code), 18 internal computer networks, 36 mainframe computers and 62 tactical warfighter-in-the-loop simulator consoles.

<u>PE 0308601F Modeling and Simulation Support</u>

This program element will support the transition from legacy M&S systems in the USAF to emerging DoD standards, models and architecture. Models are being modified or developed for a wide variety of areas, including RDT&E, acquisition and training. This project also supports the USAF portion of the Aggregate Level Simulation Protocol (ALSP), Data Standards, Advanced Connectivity, model verification, validation and accreditation (VV&A) and High Level Architecture (HLA). Projects include:

- Project #1011 Joint Modeling Transition Program

- Project #4566 Executive Agent for Air/Space Natural Environment

PE 0601192F Defense Research Sciences

Project #2304 Mathematical and Computer Sciences – This research focuses on mathematical modeling, simulation and control of complex systems, including, among other areas:

- Effective utilization of high performance computers
- Models and computational tools for the design of aircraft, missiles or other weapons
- Efficient production of large-scale, well-documented computer programs and software

Project #2313 Human Performance – This project consists of research on information processing in humans and other organisms including computer image and speech processing, human interface, sensors and sensor fusion. Emphasis is placed on sensory systems, including:

- Vision and audition
- Cognition, perception, and intelligent tutors
- Team situational awareness

PE 0602202F Human Effectiveness Applied Research

This program element addresses several areas with relevance to simulation and training, including development of human interface needs for weapon systems, operational readiness and environment quality. Crew systems technologies increase the performance of humans by improving aircrew life support systems, man-machine integration and protection from dynamic forces. The goal is to improve combat effectiveness by expanding all parameters defining occupational performance limits.

Project #1123 Manpower, Personnel and Training – This project develops and evaluates new methods in support of USAF training and education, including aircrew training, technical training, logistics training, mission rehearsal, training in support of complex decision-making, information warfare training, and warfare readiness training. It develops and evaluates specific training systems, desktop tutors, performance assessment systems, courseware development tools and technologies, assessment methodologies, and simulation-based systems.

PE 06044227F Distributed Mission Training (DMT)

This program element is responsible for flight simulation, including the development of aircrew and maintenance training devices. The objective is to adapt simulation technologies and standards developed by USAF laboratories and industry to prototype training devices to satisfy MAJCOM training requirements. DMT will modernize USAF flight simulators and network geographically dispersed, high fidelity aircraft simulators

with other battlefield systems into a real-time synthetic battlefield. This will become a virtual network capable of training systems, which will allow training not possible using other simulators. One focus of DMT is to provide mission rehearsal capabilities and training to USAF warfighters in home stations, linking dissimilar aircraft simulators in real-time for practice of complex maneuvers and critical timing aspects for operations.

(D) Other Department of Defense (DoD) Organizations

This section describes some of the simulation efforts underway in other DoD entities, exclusive of the three major service branches. These include the following:

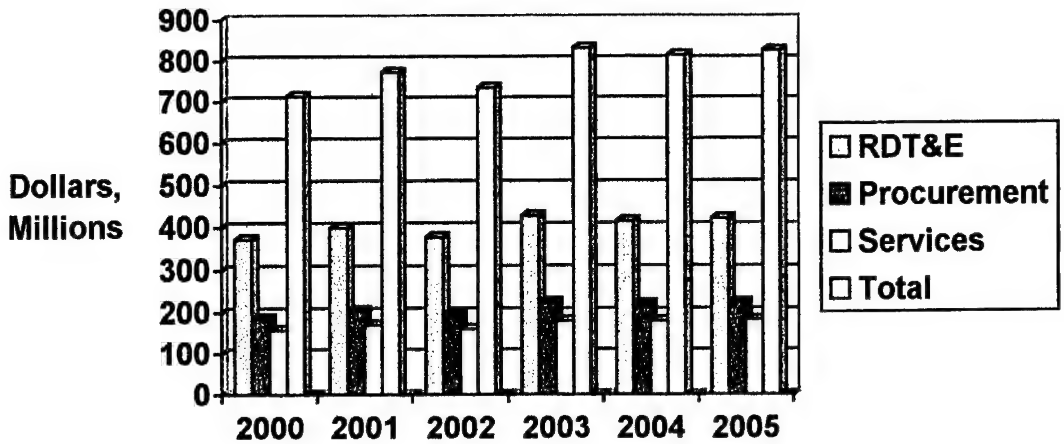
- Defense Advanced Research Projects Agency (DARPA)
- Ballistic Missile Defense Organization (BMDO)
- Office of the Secretary of Defense (OSD)
- Chemical and Biological Defense Program (CBDP)
- Defense Information Systems Agency (DISA)
- Defense Logistics Agency
- Defense-Wide Operational Test and Evaluation (DOT&E) and Developmental Test and Evaluation (DT&E)
- Defense Security Cooperation Agency (DSCA)
- Defense Threat reduction Agency (DTRA)
- Joint Chiefs of Staff (JCS)
- Special Operations Command (SOCOM)

Programs at DARPA, BMDO, DSIA and JCS were examined in more detail because they include simulators with relevance to the current analysis.

1) Budget

The current budget, components and forecasts for other DoD organizations in simulation and training are shown in Figure #10.

Figure #10: Forecast Estimate and Segmentation of Simulation Budget, Other DoD Organizations, 2000-2005



2) Defense Advanced Research Projects Agency (DARPA)

DARPA is the central research and development organization for the U.S. military. DARPA manages and directs selected basic and applied research and development projects for DoD, and pursues research and technology where risk and payoff are both very high and where success may provide dramatic advances for traditional military roles, missions, and dual-use applications.

<u>PE 060211E: Next Generation Internet</u>

The Next Generation Internet (NGI) initiative will develop novel network capabilities to enable a new wave of revolutionary applications. DARPA's role in NGI will involve: experimental research for advanced network technologies and the development of ultra-high speed switching and transmission technologies that lay the groundwork for terabit per second (Tb/s) networks. The former activity will be organized into two components referred to as Network Engineering and Quorum. The latter is referred to as SuperNet.

- The objective of the Network Engineering component is to create a networking architecture and tools that greatly automate planning and reduce support functions, thus enabling the growth of networks by a factor of 100 or more while lowering the cost of network management.

- The Quorum component of NGI is defining a revolutionary approach to network-

based computing that positions adaptive quality-of-service (QoS) management as its central architectural principal. Quorum emphasizes the end system software aspects of this problem. As such, it is primarily concerned with leveraging enabling network services by coupling them to the application from the network interface through operating systems, middleware, and resource management layers.

- The objective of the SuperNet component is to develop ultra-high speed multiplexing and transmission technologies together with advanced configuration management and control capabilities, and demonstrate end-to-end network connectivity involving tens of sites (nodes) and applications.

Development of these three component technologies will provide the pathway to terabit per second networks, supported by the appropriate network management and control function with assured end-to-end service.

PE 0602301E Computing Systems and Communications Technology

Project #ST-19 High Performance and Global Scale – This project is designed to develop the computing, networking and associated software technology base underlying the solutions to computational and information-intensive applications for future defense and federal needs. This includes a demonstration of STOW using scaleable advanced distributed simulation (ADS) involving some 50,000 entities. In 1999, this project included system level design and simulation review of ultrascale computing applications.

PE 0603761 Communications and Simulation Technology

This program element is designed to demonstrate and evaluate advanced simulation technologies and networking systems that will seamlessly integrate command and control functions needed for future global defense operations. Projects have included Advanced Simulation, which contains an Advanced Concept Technology Demonstration (ACTD) on the Synthetic Theater of War (STOW), and the Defense Simulation Internet (DSI).

3) Ballistic Missile Defense Organization (BMDO)

Within the Department of Defense, the Ballistic Missile Defense Organization (BMDO) is responsible for managing, directing, and executing the Ballistic Missile Defense (BMD) Program. The BMD program's objective is to: first, develop and deploy increasingly capable Theater Missile Defenses (TMD) to meet the existing missile threat to deployed U.S. and allied forces; second, as a hedge against the emergence of long-range ballistic missile threats, develop options to deploy a National Missile Defense (NMD) for the United States; and third, continue to support research on more advanced ballistic missile defense technologies to keep pace with the threat and improve the performance of theater and NMD systems.

PE 0603871C National Missile Defense

The National Missile Defense (NMD) system is being developed to protect the United States against a limited attack by long-range ballistic missiles. A decision whether to deploy the fixed, land based system will be made in mid-2000 and will be based on technology development, affordability, the potential threat, international treaty considerations and competing defense priorities. The key NMD components include a ground based interceptor (GBI), and X-band radar (XBR), Upgraded Early Warning Radars, Battle Management/Command, Control and Communications (BM/C3) and space sensor technology

Project #3352 Modeling and Simulation – This project ensures the timely availability of reliable, cooperative and cost-effective BMDO and Service-provided Modeling, Simulation and Networks (MS&N) tools and capabilities responsive to BMDO requirements. The project:

- Provides for the planning, coordination, program management and technical oversight of system MS&N for the Theater Air Missile Defense (TAMD) and National Missile Defense (NMD) Deployment Readiness Programs.

- Funds the development, operation and Verification, Validation and Accreditation (VV&A) of the Extended Air Defense Bed (EADTB) and the Extended Air Defense Simulation (EADSIM) simulations. The EADTB is a flexible distributed simulation tool that can determine the performance of existing and conceptual extended air and missile defense with the added complexity of theater missile defenses. This is a multi-site test environment that is comprised of high and medium fidelity models of sensors, environments, weapon systems, threats, and Battle management Command, Control and Communications.

4) Office of the Secretary of Defense (OSD)

The Secretary of Defense is the principal defense policy advisor to the President and is responsible for the formulation of general defense policy and policy of all matters related directly to DoD.

PE 0603832D Joint Wargaming Simulation Management Office

The Defense Modeling and Simulation office (DMSO) has developed a strategy embodied in the DoD Modeling and Simulation Master Plan. The budget for this office in 2000 was approximately $68 million. The Master Plan contains the following elements:

- High Level Architecture (HLA)
- Conceptual Models of Mission Space
- Data Standardization

5) Defense Information Systems Agency (DISA)

The mission of DISA is to plan, engineer, develop, test, manage programs, acquire, implement, operate, and maintain information systems for C4I and mission support under all conditions of peace and war. As the manager of the Defense Information Infrastructure (DII), DISA integrates hardware and software and develops a common operating environment to sustain warfighters need for information anytime, anywhere. The pillars of the DII are the Defense Information System Network, the Defense Message System, the Global Command and Control System, and the Global Combat Support System. DISA also helps protect against, detect and react to threats to both its information infrastructure and information sources.

PE 0302019K Defense Information Infrastructure Engineering and Integration

Project #E62 Modeling and Simulation – This effort supports the DoD communications planning and investment strategy by providing modeling and simulation tools to DoD decision makers.

6) Joint Chiefs of Staff

The Joint Chiefs of Staff consist of the Chairman, the Vice Chairman, the Chief of Staff of the Army, the Chief of Naval Operations, the Chief of Staff of the Air Force, and the Commandant of the Marine Corps. The collective body of the JCS is headed by the Chairman (or the Vice Chairman in the Chairman's absence), who sets the agenda and presides over JCS meetings. Responsibilities as members of the Joint Chiefs of Staff take precedence over duties as the Chiefs of Military Services. The Chairman of the Joint Chiefs of Staff is the principal military adviser to the President, Secretary of Defense, and the National Security Council (NSC), however, all JCS members are by law military advisers, and they may respond to a request or voluntarily submit, through the Chairman, advice or opinions to the President, the Secretary of Defense, or NSC.

PE 0902740 Joint Simulation System (JSIMS)

JSIMS is a single, seamlessly integrated simulation environment designed to train Commanders in Chief (CINCs) and Services to meet the Chairman's Joint Training System requirements. It includes core infrastructure and mission space objects, both maintained as a common repository. The objects can be composed to create a simulation capability to support joint or Service training, rehearsal or education.

JSIMS is a core of common and joint representations and services, a runtime hardware and software infrastructure, interfaces, and representations of Air/Space, Land and Maritime Warfare functionality. JSIMS includes a strategy for specific representations.

B. Current Simulators

Information was collected on the current simulation systems used by the U.S. military for non-medical applications. Jane's Simulation and Training Systems, 1998-1999 (Strachan, 1998) was used as a master reference for descriptions of current military training systems. Other information was provided by DoD organizations, including STRICOM, and by manufacturers.

Simulation types:

- *Image Generators, including Personal Computer Image Generators (PC-IG) and Visual Simulation Software Tools.* These systems include those that use satellite and non-satellite aerial images, terrain and other landscape images, computer-generated images (CGI/CIG), 3D models of terrain objects, vehicles, human figures (eg, character animation) and other objects, and software tools for editing images, including image analysis (registration, segmentation, image processing), polygonal models and other types of models (surface and volume rendered models) and textures and texture-mapping.

- *Visual display and virtual reality systems.* These include computer monitors, stereoscopic displays, head-mounted displays (HMD), virtual reality displays and systems, domes, virtual workbenches, holographic displays and projection systems.

- *Motion cueing systems.* These include motion platforms for flight simulation and other applications.

- *Haptics displays.* These provide "touch and feel" feedback to the user, include force feedback, tactile displays, proprioceptive displays and combined systems.

- *Tracking systems and sensors.* These use electromagnetic, infrared and other sensors for tracking movement and other features of the user.

- *Controls devices and panels.* These include joysticks, wheels, pedals, mice, control loading systems, instruments and instrument panels, instrumented gloves, sound and audio.

Figures #11, 12 and 13 shows training simulators that were used by the U.S. military during 1998-1999 and which have been listed, studied and/or reviewed in the current analysis. Certain simulators were not included in the present analysis, including multi-role simulators, motion cueing devices, entertainment simulators, range targets, commercial flight simulators, Distributed Interactive Simulation (DIS) systems lacking a device-training component, computer-based instruction lacking a simulation component, embedded system trainers, traffic control and certain operational simulators.

Table #11: Review of Land-Based Simulators Used by the U.S. Military, 1998-1999

Simulation Type	Simulation Systems
Anti-Armor Weapon Systems	• Direct Fire Laser Simulators (FATS Inc) • Precision Gunnery Training System (Fairchild) • TOW Gunnery Trainer (Kollsman) • Training Devices for the Javelin Anti-Tank Missile (ECC International Corp) • US Army Virtual Anti-Armor Simulation (STRICOM)
Air Defense Simulators	• DME Stinger Simulator (STRICOM) • Moving Target Simulator, MTS-II Dome (AAI Corp) • Operator Tactics Trainer, OTT (Sanders Patriot Missile System) • Portable Air Defense threat Simulators, PADS (DBA Systems) • Stinger Training Simulator, STS (Kollsman, Simtech) • Stinger Troop Proficiency Trainer (Kollsman, Simtech)
Direct Fire Simulators	• Conduct of Fire Simulators (Kollsman) • Direct Fire Simulators (Lockheed Martin) • Full Crew Interactive Trainers, FIST (CSC; IDL Corp) • Gunnery Trainers (Perceptronics Corp) • Reconfigurable Combat Vehicle Simulators, RCVS (TSI, Inc) • Thru-Sight Video (TSV) for Armor Fighting Vehicles (EFW Corp)
Driver Training Simulators	• Close Combat Tactical Trainer, CCTT (Lockheed Martin Information Systems) • DS600 Driver Simulator (ETC) • Tank Driving Simulator, TDT2000 (Lockheed Martin Information Systems) • TT150 Driving Simulator (Perceptronics Corp)
Indirect Fire Simulators	• Fire Support Combined Arms Tactical Trainer, FSCATT (Raytheon) • Howitzer Strap-on Training, HSOT (AAI Corp) • M109A6 Paladin Howitzer Training Devices (ECC International Corp) • FATS Indirect Fire Simulator (ECC International Corp)
Maintenance Trainers for Land-based Equipment	• Maintenance Simulators (DME Corp) • Maintenance Training System, STS (Contraves-SSI) • Maintenance Trainers, including Abrams Tank Turret Organizational Maintenance Trainer, TTOMT (ECC Corp)
Small Arms Simulators	• FATS trainers for small arms (FATS, Inc) • Firearms Simulation Systems, FSS, small arms simulators (FSS, Inc) • Red Gun training systems (ASP, Inc) • SBS firearms trainers (SBS Technologies, Inc) • Soldier Visualization System, SVS (Reality By Design, Inc) • Spartonics Weaponeer M66/70 marksmanship training systems (Spartonics) • SwRI small arms simulators (SwRI) • Veda Distributed Soldier Simulation, DSS (Veda, Inc)
Tactical Engagement Simulation (TES)	• Cubic MILES 2000 tactical engagement system (CDS, Inc) • MILES tactical engagement simulation (Lockheed Martin Information Systems)

Source: Jane's Simulation and Training Systems, 1998-1999; DoD.

Figure #12: Review of Ship Simulators Used by the U.S. Military, 1998-1999

Simulation Type	Simulation Systems
Ship's Bridge and Handling Simulators	• Advanced Marine Virtual Ship (VS) series of ship handling simulators (AME, Inc) • ECO CAPTAINS ship maneuvering training system • FTI bridge and Combat Center (CIC) trainer (FTI, Inc) • MarineSafety (MSI) ship handling simulation (MSI Inc) • Raytheon Full Mission Trainer for the Landing Craft Air Cushion (Raytheon) • Ship Analytics Full Mission Handling Simulator, FMSS (SAI Inc)
Ship Maintenance Trainers	• ASW combat system maintenance trainer (AAI) • DynaLantic RAST maintenance trainer • Mark 92 fire-control maintenance trainer (Lockheed Martin) • Raytheon Trident Sonar Maintenance Trainer, TSMT (Raytheon) • Gun and launcher maintenance trainers (United Defense LP)
Ship Mine Warfare	• Raytheon Mine Warfare Simulator, MWSim (Raytheon)
Ship Propulsion Simulators	• DynaLantic gas turbine propulsion plant trainers (DynaLantic) • Raytheon ship gas turbine propulsion plant trainer (Raytheon)
Ship RF and EW Simulators	• AAI ship radar and EW simulators (AAI Corp) • Comptek ship and EW simulators (Comptek Federal Systems Inc) • Delex IR/RF decoy deployment trainer (Delex Systems Inc) • Logicon RF Simulators (Logicon Corp) • Ship Analytics radar simulator (SAI Inc) • Sonoalysts Radar System Controller Intelligent Training Aid (Sonalysts Inc) • US Navy – Naval Surface Warfare Center (NSWC) simulators and trainers
Ship Sonar and Acoustic Simulators	• Computer Sciences Q-321 sonar emulator (CSC) • DRS sonar training sets (DRS Electronics Systems Inc) • Lockheed Martin Sonar Trainers (Lockheed Martin) • NAWC/TSD Diver Hand-Held Sonar Trainer, DHST (Naval Air Warfare Center) • PSI sonar and acoustical trainers (PSI Inc) • Raytheon sonar trainers (Raytheon) • Sonalysts sonar trainers (Sonalysts Inc)
Ship's Weapons Simulators	• Delex Systems Harpoon trainers (Delex Systems Inc) • FATS Vessel Weapon Engagement Training System, VWETS (FATS Inc) • FTI naval gunfire observer trainer (FTI) • Naval weapon trainers (United Defense LP) • US Navy NWSC weapon simulators
Submarine Simulators	• DynaLantic SSN-21 Seawolf ship control operator trainer (DynaLantic) • Johns Hopkins APL – submarine ship control training program • Raytheon submarine trainers (Raytheon)
Underwater Simulators	• Lockheed Martin underwater submarine simulator (Lockheed Martin) • Northrup Grumman Self-Propelled Acoustic Target, SPAT (Northrup Grumman) • HOTTorp launch training torpedo (Raytheon) • Sippican Expendable Mobile ASW Training Target (Sippican Inc)

Source: Jane's Simulation and Training Systems, 1998-1999; DoD.

Figure #13: Review of Flight Simulators Used by the U.S. Military, 1998-1999

Simulation Type	Simulation Systems
Parachute Simulator	• STI virtual reality parachute simulator (STI Inc)
Flight Simulators	• AAI flight simulators and Flight Training Devices (AAI Corp) • Ball Aerospace Flight Training Devices (BATC) • Binghamton Simulator Company flight simulation (BSC) • Boeing Flight Simulation (Boeing Company) • Camber Simulation Flight Training Devices (CSS) • Delex Flight Training Devices (Delex Corp) • ECC Flight Training Devices (ECC International Corp) • ETC Flight Training Devices and centrifuges (ETC) • FAAC flight simulation devices (FAAC) • FlightSafety international flight simulators (FSI) • Frasca flight simulators and Flight Training Devices (Frasca International Inc) • FTI flight simulators and Flight Training Devices (FTI) • Intergraph flight training demonstrators (Intergraph Corp) • Lockheed Martin F-16, Orlando, Akron and TTS flight simulation (LMIS) • McDonnell Douglas flight simulation (MDTS) • Opinicus flight simulation (Opinicus Corp) • Perceptronics Avionics Situational Awareness Trainer, ASAT (Perceptronics) • Reflectone flight simulation (Reflectone Inc) • Raytheon Air Force Air Force fixed-wing flight simulation (Raytheon) • Raytheon flight simulation and FTDs for Navy fixed-wing aircraft (Raytheon) • Raytheon general flight simulation, rotary-wing and NASA projects (Raytheon) • Sikorsky Comanche Portable Cockpit (CPC) simulator (Sikorsky Aircraft Inc) • S&SI dynamic helicopter trainer (S&SI) • SIMTEC flight training devices (SIMTEC) • SSAI flight training and simulation systems (SSAI) • STS flight training devices (STS) • Symvionics flight training devices (SSAI) • USAF Aeronautical Systems Center (ASC) and Air Force Research Laboratory (AFRL) simulators • US Navy, Air Combat Environment Test and Envisonment Facility (ACETEF) • US Navy, NAWC TSD simulations
Ground-based Trainers for Non-Pilot Aircrew	• AAI UNFO radar Training System (AAI Corp) • Binghamton Simulation Company Aerial Gunner Scanner Simulator, AGSS (BSC) • Lockheed Martin Target Sight Selected Task Trainer, TSTT (LMIS) • Reflectone Trainer for EA-6B tactical crew (Reflectone) • STS Cargo Compartment Trainer for C-17 loadmaster training (STS) • SwRI AWACS Modeling and Simulation (AMS) training system (SwRI)
Maintenance Trainers for Air Systems	• AAI aircraft maintenance trainers (AAI Corp) • Boeing maintenance trainers (Boeing Company) • Delex aircraft maintenance simulators (Delex Corp) • DynaLantic aircraft maintenance simulators (DynaLantic) • ECC maintemnance simulators (ECC) • ETC aircraft maintenance trainers (ETC), and others

Source: Jane's Simulation and Training Systems, 1998-1999; DoD.

C. Trends in Simulation that will Impact Medical Simulation

This is a time of tremendous time for change in simulation technology and its implementation in the military and civilian sectors. Budgets for military simulation are relatively stable and will grow slightly over the next 5 years, but the impact of new technologies in visual simulation such as photo-realistic rendering, high speed networking, distributed simulation and distance training, and increases in computing power will greatly increase the utility, fidelity and value of real-time simulation for training, education and mission rehearsal. At the same time, the efficacy of simulation-based training will reduce budgets for simulation and training, leading to decreased spending on these technologies. In other domains, the value of simulation for acquisition and RDT&E will enhance the broader applicability of simulation for a variety of purposes in the military and elsewhere.

There are a number of trends in the broader simulation arena that will impact medical simulation training in the military. These include:

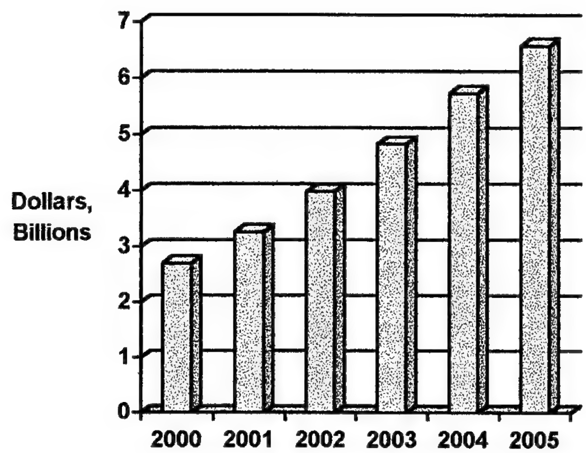
- Emergence of personal computer image-generators (PC-IG) as an inexpensive platform for visual simulation. These affordable machines are changing the face of simulation, supporting a variety of military and commercial applications where the cost of visual simulation had previously outweighed the benefits. This trend will also drive continuing adoption of Windows NT (Windows 2000) as the operating system for many applications in simulation, although many developers prefer Linux or UNIX operating systems. Older applications developed in the IRIX (Silicon Graphics, Inc.) or UNIX environments will be ported to the PC, and these platforms will continue to become obsolete except for the most computationally-demanding applications. Similarly, the development of powerful graphics subsystems, such as the nVidia and other chipsets for gaming applications, will further enhance the visual simulation capabilities of the PC, supporting rendering of high fidelity 3D models, volume rendering and other medical simulation requirements.

- Adoption of High Level Architecture (HLA) and other standards allows for rapid development and interoperability of simulation applications. The open architecture, HLA standard developed by the U.S. military, based on Distributed Interactive Simulation (DIS), has led to a rapid increase in simulator development. The open environment has encouraged niche developers and overthrown the proprietary stranglehold concentrated in the hands of a few developers by providing a common interoperable system for development. Similarly, the OpenGL (Graphics Library) standard developed by Silicon Graphics, Inc. stimulated growth of simulator development through innovation.

- Development of photo-realistic imaging for terrain rendering and other applications in military simulation. The ability to use actual photographic images of actual place as texture maps for terrain mapping has greatly enhanced the fidelity of wargaming and other simulation systems. Elements of this technology should be combined with diagnostic images to enhance fidelity of medical simulators

➢ Tremendous growth of worldwide markets in visual simulation predicted over the next 5 years. Figure #14 shows the forecasted growth of simulation markets over the next 5 years. This substantial growth includes the emergence of many new developers of new hardware and software in the visual simulation arena, with over 50% of market participants entering this arena during the last 4 years. This will greatly impact the pace of medical simulation development, by providing an increasing base of technology developers and installed base of hardware and software for running medical simulation applications.

Figure #14: Forecast for World Visual Simulation Markets, 2000-2005



Data from Frost & Sullivan, March 2000.

➢ Realization of Distributed Interactive Simulation (DIS) and other high performance computing and networking applications. The promise of DIS in the early 1990's is being to be realized through the development of large joint simulation systems such as JSMIS in the military and the Internet-2 project in the civilian sector. This infrastructure will provide the backbone necessary to run new, distributed applications in medical simulation, and should be leveraged for the military medical domain. Similarly, the increased emphasis placed on Advanced Distributed Learning (ADL) as a priority in DoD for the development of cognitive training, distributed performance and distance learning applications emphasizes the importance of these network-based technologies for the future of simulation in the military.

➢ Simulated training proves to be more valuable than live training, in terms of both cost and efficacy in the military. The cost advantages of simulated training have been realized to such an extent that the military are cutting budgets for live training exercises and other non-simulation training applications. For example, the use of After Action Review (AAR) after simulation training has proved to be an

extremely valuable mechanism for performance review, providing trainees the opportunity to view their performance from different angles and view, and visualize their performance compared with that of other trainees and experts. Other unexpected applications of simulation, such as simulation-based acquisition, promise to greatly reduce costs even further.

- Cost benefit of simulation enhances development of RDT&E including virtual prototyping. The use of simulation for testing different device and equipment designs has proved to be a very valuable technology in the military, and is now spreading to other domains such as aerospace, automotive, ship-building, architecture, civil engineering, factory automation and energy industries. This is also expected to prove valuable for medical applications such as medical device and prosthetic/implant design and development.

- Continuing increases in computing power and parallel processing will make real-time rendering of even large and complex datasets a reality. The impact of Moore's law, doubling computing power every 18 months, will continue to enhance the processing power of computing platforms. Parallel and distributed processing will bring the power of supercomputing to smaller, Windows-based systems, enabling computing intensive applications such as volume rendering.

IV. Guidelines and Recommendations

Lessons from the military experience with simulation can be used to guide development of a medical simulation-training program in combat readiness. There is a wealth of information that can guide developers of medical simulation training systems, but many efforts to date have not incorporated these design principles. This section is organized as General Guidelines based on previous military simulation training studies coupled with Specific Recommendations for medical simulation for combat trauma training.

Overview of Guidelines and Recommendations

Guidelines:

1) Training should be focused on the needs of the user, not on the technology.

2) Accurate performance measures are critical to simulator effectiveness.

3) Hybrid combinations of different simulation technologies often provide the most effective training instruments.

4) Although simulator fidelity is often important for user acceptance, it is not required for successful training.

5) Part task training is best suited for training procedural skills.

Recommendations:

- Emphasis should be placed on life-saving procedures in combat trauma, not on laparoscopic/minimally invasive procedures.
- Specific procedures and skills in trauma training should be identified, and task analysis should be used to identify critical components.
- Critical procedural elements should be selected for the development of Part Task Trainers and performance assessment.
- Simulator design should be driven by users and trainers from the military, as well as trauma experts from the civilian environment.
- Hybrid technology applications, including virtual environments, mannequin and real world medical training, should be combined for the optimal training solution.

Medical Trainers Should Manage Medical Simulation in the Military

Although many important lessons can be learned from the military experience with simulation, medicine has very different training requirements. Specifically, it is recommended that responsibility for the management of medical modeling and simulation efforts be managed by medical trainers in the military, not by traditional military Modeling & Simulation management vehicles.

Detailed Guidelines and Recommendations:

(1) Training Integration is Important

- Guideline*: Simulators must be integrated into a training plan to be effective. Without training integration, military personnel will not use simulators.*

  There are many examples of poor simulator utilization resulting from a lack of training integration (see Orlansky et al, 1994 for examples). In the medical domain, it is important to make sure that simulator training is developed in close collaboration with content developers. Trainees must also understand that performance on simulators is a required part of successful training.

- *Recommendation:* Simulator design should be driven by users and trainers from the military (eg, combat medics, nurses, emergency physicians, trauma surgeons), as well as trauma experts from the civilian environment.

(2) Performance Assessment is Critical

- *Guidelines:* Accurate, quantitative performance measures are critical to simulator effectiveness. Users must be clear about how their performance meets operational requirements.

  Performance assessment is a requirement for effective simulation training (Copenhaver et al, 1996; Hays et al, 1992a; Hettinger et al, 1995; Jacobs et al, 1990; Marcus and Curran, 1988; McCauley and Cotton, 1982; Orlansky et al, 1997; Westra et al, 1982). Characterizing performance measures for medical simulator development is a tedious and time-consuming process, involving task and skills analysis. Objective metrics of cognitive, perceptual and motor skills must be developed for individual medical procedures. These include performance measures such as timing, accuracy, tissue damage, instrument handling, applied force, cognitive decision-making and others. The simulation training literature clearly demonstrates that users benefit from performance feedback, indeed simulation cannot function effectively without it. Military training is most effective when users are clear that successful performance on the simulator is tied to successful completion of the training requirement (Orlansky et al, 1994).

- *Recommendations:* Senior medical personnel should be responsible for the development of performance metrics. These metrics should be developed in coordination with professional credentialing entities in the military and civilian environments to insure the validity of performance criteria. Performance assessment features must be integrated into medical simulator development.

(3) Hybrid Simulators Often Provide the Most Effective Training Instruments

- *Guideline:* Hybrid combinations of different simulation technologies, coupled with real world environments, often provide the most effective training instruments.

  An appropriate mixture of simulation technologies must be chosen that is best suited to the task. Hybrid solutions combining have been shown to be ideal in many cases, especially when the technology cannot realistically reproduce critical procedural components (Orlansky et al, 1997).

- *Recommendation:* Hybrid technology applications, including virtual environments, mannequin and real world medical training, should be integrated in a procedure and skill-specific fashion to provide the optimal training solution.

(4) Fidelity is Not Necessary for Effective Training, Although it may Help User Acceptance

- *Guideline:* Simulator fidelity is not necessarily important for successful training in all cases. Many investigators have found that simulators with low physical fidelity train as effectively as high fidelity simulators. Simulators that provide the most realistic fidelity are most warmly embraced by users.

  There is a large body of literature showing that high levels of physical fidelity are not necessary for simulator training effectiveness, especially for procedural and part task trainers (Advisory Group, 1980; Durrall et al, 1978; Edwards, 1986; Hays and Singer, 1989; Hays et al, 1992a; Knerr et al, 1986; Lintern et al, 1990; Lintern et al, 1998; Moroney and Moroney, 1998; ; Sawyer et al, 1982; Westra et al, 1982, 1986). Instead, functional fidelity is important – the focus must be placed on simulator design for effective training of the task at hand. Respected content experts must be involved in determining appropriate levels of realism and fidelity required for user acceptance. Experienced trauma and medical personnel must guide medical simulator design in developing face validity that will appeal to the user.

- *Recommendation:* Senior medical personnel and human factors experts should be responsible for the evaluation of simulator fidelity for new products and technologies. Fidelity must be matched to requirements of the simulated medical procedure.

(5) Training Should be Focused on the Needs of the User, Not on Technology

- *Guideline:* Simulation technology must be matched with the appropriate training requirements. Adoption of new technology without training applicability often produces poor results.

  Simulation technologies must be matched to the requirements of the specific medical procedures and skills that are being trained. New technologies should be evaluated by instructors before introduction into the training regimen (Knerr et al, 1986; Spears et al, 1982).

  Recommendation: Specific procedures and skills in trauma training should be identified, and prioritized based on military medical need and simulation technology limitations. Emphasis should be placed on life-saving procedures in combat medicine and trauma surgery, not on minimally invasive procedures with little relevance to the combat environment. Critical procedural elements should be selected for the development of Part Task Trainers.

(6) Part Task Training is Best Suited for Training Procedural Skills

- *Guideline:* Part Task Trainers (PTT) are generally more effective than Whole Task Trainers (WTT) and Operational Trainers (OT) for training procedural skills. PTT also are most useful for novice and intermediate skill training.

  The effectiveness of PTT for many aspects of procedural training has been shown in several studies (Sheppard et al, 1985; Knerr et al, 1986; Moroney and Moroney, 1998; Carretta and Dunlap, 1998). Given that combat medicine involves procedures, emphasis must be placed on the development of PTT for training trauma skills. Medical procedures must be broken down using task analysis to determine the critical tasks to be trained using PTT technology (Meyers et al, 1987).

- *Recommendation:* Trauma procedures should be deconstructed to identify critical skills necessary for successful performance. These critical procedural elements should be selected for the development of Part Task Trainers.

(7) Virtual Environments (VE) are Important for Training Spatial Skills

- *Guideline:* Simulators are most useful for training cognitive and perceptual skills related to spatial tasks such as carrier landing and jet fighter combat. VE simulation is ideal for training spatial orientation and situational awareness.

  Emphasis in the medical domain should be placed on the development of spatial orientation and navigational tasks using virtual environment (VE) technology. Numerous studies have demonstrated the utility of VE training for spatial and

navigational skills (Hettinger et al, 1995, 1995, 1996; Durlach and Movay, 1995). See also Westra et al, 1981, 1982 and 1986.

- *Recommendation:* Virtual environment (VE) simulators should be developed to provide enhanced training in situational awareness, spatial visualization of anatomy and device-tissue interaction, and to provide the user with stressors appropriate to the combat environment.

(8) Case Scenarios Enhance Training Effectiveness

- *Guideline:* Simulation training can be enhanced by providing the user with a library database of case studies, including virtual and live data performance from other users.

  The literature suggests that training databases greatly enhance student performance, by introducing other information from case studies and allowing the student to compare elements of their performance with those of other users (Sterling, 1997; Orlansky, 1994).

- *Recommendation:* Databases of actual trauma case studies must be developed to provide the end-user with enhanced instruction. These should be developed to provide a realistic basis for fully integrated scenarios.

(9) Simulators Should Provide Advanced Instructional Features

- *Guideline:* Simulation training benefits greatly from 'advanced instructional features' that cannot be provided to the user in the real world setting.

  Attributes such as simple VCR-like functions like 'rewind' and more advanced features such as 'Above Real Time Training' can provide enhanced training and best exploit the capabilities of the simulation environment (Carretta and Dunlap, 1998; Polzella et al, 1987; Westra et al, 1986).

- *Recommendation:* Senior trauma personnel need to identify cognitive, perceptual and motor skills that can benefit from advanced, computer-based instructional training.

(10) Simulators Should Incorporate Attributes of the Real World

- *Guideline:* Simulators should be designed to incorporate as many attributes of real world equipment and setting as possible.

  Trainers are most effective when they are closely linked to the actual procedures, devices and environment that are being simulated (Hays et al, 1992). Embedded simulators such as aircraft-based flight simulators are effective training instruments (Strachan, 1998).

- *Recommendation:* Medical simulators should incorporate actual medical devices whenever possible, and environmental features of the combat environment, including stressors, should be built into the simulation environment.

(11) Simulators Should Provide a Flexible Platform for Training in New Procedures

- *Guideline:* The most effective training occurs during the first 25 or so times a student uses a simulator. Simulators also provide an ideal way for introducing new techniques and equipment to experienced users.

  Simulators should be used for 'ab initio' training, and for training experienced operators in new procedures and technologies (Carretta and Dunlap, 1998). Transfer effectiveness is greatest when new tasks are introduced to the student (Taylor et al, 1997).

- *Recommendation:* 'Ab initio' training should be emphasized. Medical personnel and technologists need to provide an ongoing source of new procedural and device training simulations for the end-user. Simulators should be configured to accommodate training in different procedures and new technologies.

(12) Simulators Should be Deployable and Reliable

- *Guideline:* Simulators should be rugged, portable and deployable across a number of units. Flexible, low-cost systems often work better than large dedicated systems.

  Rugged, inexpensive PC-based systems should be used where possible (Orlansky, 1994; Taylor et al, 1997). Simulators should be reconfigurable for training in a variety of medical procedures and skills.

- *Recommendation:* Whenever possible, simulators should be developed to provide a flexible configuration and universal platform. Examples of reconfigurable simulators include the virtual workbench and web-based applications.

(13) Simulators Should be Periodically Evaluated for Effectiveness

- *Guideline:* Simulators should be periodically evaluated for training efficacy and cost-effectiveness.

  Evaluation provides simulation engineers and trainers with guidance on future development, and justifies expenditures in the cost-constrained acquisition environment (Orlansky, 1994).

- *Recommendation:* Mechanisms must be implemented to evaluate the training efficacy and utility of medical simulation systems, to provide feedback for simulator improvement and to track costs associated with simulator deployment.

V. Strategic Plan for Medical Simulation in the Military

A. Overview and Analysis

This chapter provides background and vision for the design and development of medical simulation-based training in the military. The emphasis is placed on training requirements and global design issues, rather than detailing a blueprint for proposed systems engineering efforts.

Section B explains differences between non-medical and medical simulation, and makes an argument why medical simulation should be guided by medical training components in the military. Section C, 'Training Requirements' describes the near term challenges for the training of medical skills in the military. The Army 91W combat medic is used as the model for training requirements, because these individuals and their counterparts in the other services represent the largest component of the military responsible for medical readiness. Trauma skills are identified as priorities, and analogies are drawn to civilian EMT (Emergency Medical Technician) training because 91W medics will be required to be certified in EMT-Basic (EMT-B) skills. The Special Operations Combat Medic (SOCM) is used as an example of first responder "super-performers", because these individuals are required to execute a variety of surgical and invasive procedures, and their capabilities extend beyond that of the civilian EMT-Paramedic (EMT-P). It is anticipated that, in the future, all military first responders may have to perform at the EMT-P level and beyond.

Section D, 'Review of Medical Simulation in the Civilian and Military Sectors', provides a relatively detailed review of current developments in medical simulation. A review of commercial products is followed by a description of some of the more prominent military projects. It is clear from this review that these represent many "stove-pipe" projects that are not sufficiently focused on the development of effective training simulators for medical personnel. In the civilian sector, adoption of medical simulation has been slow, in part, because there is little end-user impetus to embrace these novel training instruments that are not easily integrated or justifiable in the context of traditional medical training programs. University research and development funded by the Department of Defense is concentrated on the development of better technologies in modeling, haptics and image displays, with scant attention paid to challenges in instructional design, training evaluation and integration which are equally critical for successful simulator design. Finally, recent efforts such as the Combat Trauma Patient Simulator (CTPS) and National Capital Area Center for Medical Simulation (NCAMS) are promising, but appear not to be designed to appropriately address current training requirements in the military.

Section E, 'Strategic Plan for Medical Simulation in the Military' highlights important issues that need to addressed for future and ongoing integration. These include identification of critical elements, including basic research and development challenges, approaches for evaluation of medical simulation training efficacy, future requirements for distributed simulation in the military (Advanced Distributed Learning (ADL)) and proposed development of Joint Combat Trauma Training Simulation (JOCOTTS) Centers.

B. Differences between Non-Medical and Medical Simulation

The goal of establishing computer-based simulation as a training instrument in medicine will only be realized if the technology can be shown to be an efficacious and cost-effective adjunct to conventional training methods on patients and animals. The military simulation experience provides an overwhelming preponderance of evidence that simulation provides a valuable training experience at a greatly reduced cost compared to traditional training methods. However, training in medicine differs from much of the military-based simulation training experience on equipment such as tanks and ships.

The most important difference is that the medical simulation focuses on dexterous skills and cognitive training on biological entities, ie., humans. Humans are complex biological organisms, and require more complicated simulation trainers than those required by training on airplanes or tanks. Advances in biomedicine, including human modeling and simulation, are critical to the success of the endeavor. Thus, not only must medical simulation efforts in the military be led by medical trainers, but medical simulation design and development efforts must be continually leveraged, on an ongoing basis, by basic research in diagnostic imaging, biomechanics and anatomical functional modeling, supported by programs such as the National Library of Medicine's Visible Human Project.

The best application of simulation training technology, based on the military experience, is for those procedures that benefit most from mission-critical performance in a setting that is difficult to reproduce in the real world (Brickman et al, 1999). In medicine, mission critical procedures include life-saving emergency medicine and many surgical procedures. Figure #15 shows the characteristics shared by procedures in the medical and military domains that can benefit from simulation-based training. These skills are shared by life-saving trauma procedures and air combat, where maneuvers are mission-critical and error results in catastrophic consequences, such as the death of the pilot or the patient.

Figure #15: Characteristics Shared Between Air Combat and Trauma Medicine: Skills and the Simulation Environment

- Multidimensional skills, with an emphasis on perceptually-tuned cognitive performance in a complex spatial environment
- Cognitive skills are critical for negotiating decision pathways
- Requirement for a continuum of motor performance, ranging from precise ballistic movements to steady-hand maneuvers and continuous perceptual-motor tasks
- Requirement for intense visuo-spatial navigational skills, including 3D visualization
- Need for trajectory guidance and minimization of collateral damage
- Stressful, time-dependent performance requirement
- Operator must adjust behavior in response to rapidly changing environmental cues
- Mission-critical - Failure has grave consequences (eg, death)
- Operator commands immediate mission environment with ultimate responsibility for success or failure
- Performance cannot be easily trained using other methods
- Virtual reality can be used to provide a stressful training environment

C. Training Requirements

There is a tremendous need to increase individual medical skills proficiency in trauma among combat medics, field corpsmen, physicians and other medical personnel in the military. Reasons for diminished medical readiness among military personnel include a lack of exposure to severely injured patients, few personnel left with actual combat experience, and a widening gap between the minimally invasive and specialist-based techniques of civilian surgeons and the skills required for treating wounds such as mine injuries. These problems are exacerbated among non-physician medical personnel such as medics and corpsmen, who are responsible for early treatment of battlefield injuries, and who are increasingly performing life-saving interventions such as chest tube insertion and intravenous (IV) line placement.

All military medical personnel must anticipate function in a low density, dispersed, resource-constrained, evacuation-limited environment. In this environment, the demands are high, and there is no opportunity for "on the job training". In addition, new guidelines require medics to be certified in procedures such as IV placement, but there no mechanism available in the military to evaluate an individual's performance of these procedures. The emergence of new procedures and technologies for early trauma care require that the skills of first responders in the military be continually upgraded and maintained so that they can be adequately prepared for the battlefield of the 21st century.

The numbers of military medical personnel that could be trained using simulation is large. There are now100,000 medical personnel who can benefit from training (see Figure #16). The biggest challenge is to train first responders such as medics and corpsmen, who will increasingly be asked to perform life-saving interventions.

Figure #16. Active Duty Medical Personnel by Type of Health Care Provider and Service for Fiscal Year 1997. (Source: DOD's Health Manpower Data System)

	Army	Navy	Air Force	Total
Physicians				
General surgeons	149	152	175	476
Other surgeons	178	163	204	545
Nonsurgical physicians	4,253	3,724	3,752	11,729
Subtotal	4,580	4,039	4,131	12,750
Other medical personnel				
Physician assistants	600	209	425	1,234
Nurses	3,169	3,154	4,478	10,801
Enlisted medical personnel (medics, corpsmen, etc)	28,497	22,570	22,751	73,818
Subtotal	32,266	25,933	27,654	85,853
Total	36,846	29,972	31,785	98,603

1. Army Training Challenge: The 91W Healthcare Specialist

The 91W Healthcare Specialist is based on the "Future Medic" concept developed by the AMEDD (Army Medical Department) Center and School's Directorate of Combat Development. The 91W concept draws upon successful models of first responder personnel including the Ranger and Special Forces medics, as well as civilian paramedics.

The 91W future medic is:

- An enlisted medical soldier with strengths in combat casualty care, force health protection, and limited ambulatory care.

- An extension of the physician (or physician assistant, PA), enabling these far-forward professionals to extend their care all the way to the point of injury or illness.

- Highly skilled in emergency care and capable of providing ongoing care to critical casualties on long evacuation legs.

- Expected to invest considerable time and energy maintaining and sustaining proficiency, because key medical skills are highly perishable.

The 91W Healthcare Specialist also draws on the strengths of other medical programs including the Navy hospital corpsman and Air Force medical technician. The 91W combines the technical sophistication of the Clinical Specialist (91C) with the field capability of the Medical Specialist (91B), retaining or adapting many of the fine components of both programs into the 91W Healthcare Specialist Program.

Each 91W will maintain certification as an Emergency Medical Technician – Basic (EMT-B), and some who are qualified as licensed practical nurses will be awarded the ASI of "M6". A major issue with the 91W is the cost of the conversion and the sustainment training for both the Active and Reserve Components. The Active Component will convert 13,635 Medical Specialists (91B) and 1,525 Clinical Specialists (91C) into 13,953 Combat Medics (91W), and 1,207 with ASI M6. The Reserve Component will convert 5,236 (91B) and 3,462 (91C) soldiers into 6,018 91W's and 2,680 M6's. The target date for the AC is 1 October 2007 and the date for conversion for the RC is 1 October 2009.

The 91W medic is expected to provide competent far-forward care and evacuation off the battlefield, preserve the fighting strength through preventive medicine, and assist with the basic medical needs of the deployed soldier. Despite the far-forward battlefield emphasis, the 91W will be flexible enough to serve in the varied roles faced by the Army in the next millennium. Operations other than war, peacekeeping, peacemaking, and disaster relief are just a few of the scenarios for 91W training. The emerging threat of weapons of mass destruction is also emphasized. Because of the Department of Defense emphasis on Tricare services for beneficiaries, the 91W will also be capable and competent to provide appropriate care in fixed hospitals and clinics.

The 91W training model is built on three equally important components that include medical skills, soldier skills, and clinical experience and reinforcement. The glue that binds them together is skills verification. All 91Ws will be required to hold EMT-Basic certification throughout their careers. Figure #16 shows typical medical skills of the civilian EMT-B. The EMT-B will form the foundation for the technical aspects of the 91W medic, but the skills of the 91W surpass that of an EMT-B, and actually resemble EMT-Intermediate (Figure #17). A new designator, EMT-Military (EMT-M) is being explored to emphasize the military-unique nature of the 91W skills.

Sustainment of Medical Skills Proficiency for the 91W Combat Medic

Sustainment is critical to maintaining a ready force. Sustainment will be built-in to the 91W career model, focusing on maintenance of EMT-B certification. A portion of unit training will focus on continuing education requirements needed to maintain this certification. Sergeant's time, unit training, distance learning, weekend drills and annual training will all be leveraged to complete continuing education requirements. Once every two years, 91W soldiers will be required to re-verify their skills using the familiar go/no-go format. Skills verification testing will run very much like common task testing, except that combined Army and national emergency care standards will be used. This testing will ensure a competent medic force and provide commanders and leaders with an objective evaluation of individual soldier performance. This reverification of skills with those of national EMT-B recertification standards, and will enable soldiers to meet this requirement.

The 91W has four major areas of emphasis or core competencies, including emergency care, evacuation, force health protection, and limited primary care. A primary emphasis is placed on training skills and skills verification, as emphasized in the 91W training model:

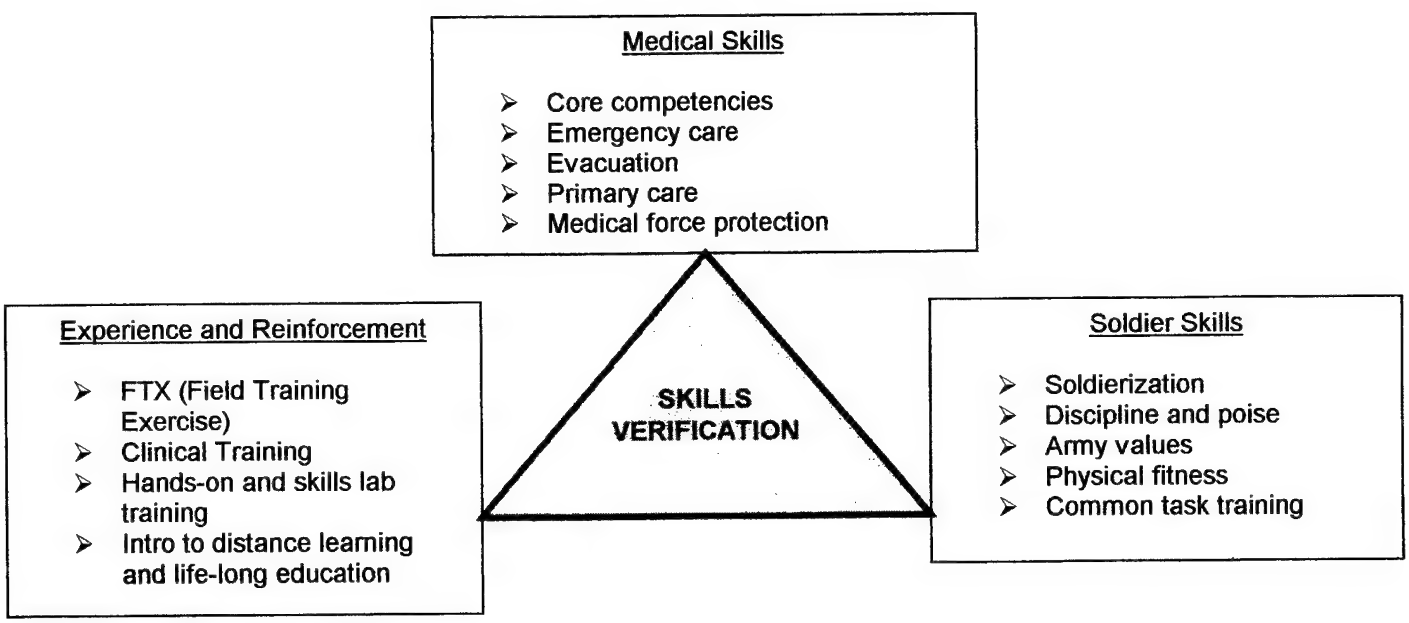


Figure #17: Examples of Skills Needed for Civilian EMT-B and EMT-I Certification

EMT-B

- Taking and recording vital signs
- Basic airway management
- Oropharyngeal airways
- Nasopharyngeal airways
- Pharyngeal suctioning
- Administration of oxygen
- Via nasal cannulas and masks
- Use of Bag Valve Mask
- Obstructed airway management and CPR, Infant, child and adult
- Managing soft tissue injuries
- Managing suspected fractures
- Managing shock
- Use of PASG
- Managing medical emergencies
- Managing environmental emergencies
- Prehospital childbirth

EMT-B with IV Skills:

- Establish Intravenous Lines (peripheral in extremities)
- Maintain Intravenous Lines (peripheral)
- Discontinue Intravenous Lines (peripheral)

EMT-Intermediate

- Cardiac manual defibrillation
- Cardiac automated defibrillation
- EKG monitoring/interpretation
- Advanced Airway Management
- Endotracheal intubation
- Tracheal suctioning
- Establish/monitor peripheral IV (extremities)
- Establish/monitor capped IV
- Infuse IV fluids (all)
- Intraosseeous Infusion
- Collect blood samples
- Administer Medications by order or in the presence of an authorized paramedic
- Administer/monitor IV drip medications
- Monitor blood/blood by-products

Source: Colorado State Board for EMT Certification

91W10 Critical Task List

The major responsibilities identified as "critical" for the 91W combat medic have been compiled into a list of targeted tasks. This Critical Task List covers a broad spectrum of diagnostic and therapeutic procedures:

1. Perform a Casualty Assessment
2. Manage an Airway
3. Treat a Casualty with a Burn Injury
4. Treat a Casualty with an Ocular Injury
5. Treat a Casualty with a Head Injury
6. Treat a Casualty with a Spine Injury
7. Treat a Casualty with a Chest Injury
8. Treat a Casualty with an Abdominal Injury
9. Treat a Casualty with an Extremity Injury
10. Treat a Casualty with an Impaled Object
11. Treat a Casualty with a Wound
12. Control Bleeding
13. Treat a Casualty for Shock
14. Treat a Casualty with Bites and Stings
15. Treat a Casualty with Anaphylaxis
16. Manage a Seizing Casualty
17. Treat a Casualty with a Cold Injury
18. Treat a Casualty with a Heat Injury
19. Manage a Behavioral Casualty
20. Extract a Casualty
21. Perform Casualty Triage
22. Evacuate a Medical Casualty
23. Assist in Vaginal Delivery
24. Treat Cardiopulmonary Symptoms
25. Treat Gastrointestinal Symptoms
26. Treat Genitourinary Symptoms
27. Treat Metabolic/Endocrine Symptoms
28. Treat Infectious Disease and Immunologic Symptoms
29. Treat Skin Disorders
30. Treat Biological Exposed Casualty
31. Treat Nuclear Exposed Casualty
32. Treat Chemical Exposed Casualty
33. Decontaminate a Casualty
34. Perform Medical Force Protection Measures
35. Perform Medical Screening
36. Perform Basic Nursing Care
37. Treat neurological symptoms

The goal of medical simulation development must address these critical tasks as a priority, as these provide the foundation for all Echelons of Care in the military.

Although 91W certification is based on civilian EMT training, there are several additional responsibilities that are undertaken by the Army combat medic.

BTLS and PHTLS

Civilian trauma training courses include Basic Trauma Life Support (BTLS) and Pre-Hospital Trauma Life Support (PHTLS), which are basic courses that are required for certification as an EMT.

The BTLS course is designed to teach prehospital care providers the skills necessary for thorough assessment, initial resuscitation, stabilization, and transport of the trauma victim. It stresses those conditions that require urgent surgical attention and thus demand immediate transport ('load and go' situation). BTLS emphasizes a rapid, organized approach to the trauma victim, and covers specific procedures and skills in assessment and triage, airway management, IV therapy, shock management, immbolization, wound treatment, chest and CNS injuries and pediatrics. The course content is usually divided into several content areas, including didactic lectures, skill stations, patient assessment situations, and a written examination.

PHTLS was developed with the Committee on Trauma of the American College of Surgeons, and stresses that the patient suffering from multisystem trauma is a unique entity with specific needs that requires an approach to treatment that varies from traditional treatment modalities. The course is designed to provide the practicing prehospital care provider with a specific body of knowledge related to the prehospital assessment and care of the trauma patient. The uniqueness of this program rests not with an entirely new body of information,but instead with advances in prehospital trauma intervention techniques. Course coverage includes kinematics of trauma, patient assessment and management, airway management and ventilation, thoracic trauma , shock and fluid retention, head trauma, extremity trauma, thermal trauma (caused by heat and cold), initial care and resuscitation (injured child), abdominal trauma in the pregnant patient, spinal trauma, special considerations (trauma of elderly) and essentials in the care of the pre-hospital trauma patient

2. Special Operations Combat Medics: Emphasis on Advanced Skills

The Special Operations combat medics (SOCM) represent what may be the future of lifesaving personnel throughout the military –delivery of advanced trauma support including surgical and interventional skills. The SOCMs include members of the U.S. Navy, U.S. Army and U.S. Air Force Special Operations, trained at the Joint Special Operations Medical Training Center (JSOMTC), 1st Special Warfare Training Group, U.S. Army John F. Kennedy Special Warfare Center and School, Ft. Bragg, NC. The JSOMTC course includes 24 weeks training for Army medics, including Special Forces (Green Berets), Ranger and Special Operations Aviation, Navy SEAL Corpsman, Marine Corps IDC and Air Force Pararescuemen.

The Special Operations combat medics receive certifications in civilian trauma courses, including, Basic Life Support, Emergency Medical Technician – Basic (EMT-B) and Advanced Cardiac Life Support (ACLS). The training goes beyond EMT-Paramedic training (see Figure #18), and includes:

- Trauma training similar to that of the 18D (Special Operations Medical Sergeant) level
- Support capabilities of sustaining team members for 72 hours
- Provision of medical support for team of 7-10 days
- Interoperability

Surgical procedures in trauma taught to Special Operations Combat Medics include:

- Wound management and repair
- Needle jet insufflation airway (needle cricothyroidotomy)
- Surgical cricothyroidomtomy
- Tubal thoracostomy
- Needle thorancentisis
- Venous cutdown
- Control of hemorrhage by vessel ligation
- Escharotomy (burns)

Figure #18: Examples of Skills Needed for Civilian EMT-P Certification

- Taking and recording vital signs
- Basic Airway Management
- Oropharyngeal airways
- Nasopharyngeal airways
- Pharyngeal suctioning
- Use of oxygen
- Cannulas
- Masks
- Use of BVM ventilation device
- Obstructed airway/CPR infant, child and adult
- Managing soft tissue injuries
- Managing suspected fractures
- Managing shock
- PASG
- Managing medical emergencies
- Anaphylactic shock - epinephrine
- Poisons-syrup of ipecac/activated charcoal
- Poisons-syrup of ipecac/activated charcoal
- Emergency childbirth
- Cardiac automated defibrillation
- EKG monitoring/interpretation
- Transcutaneous cardiac pacing
- Advanced Airway Management
- Endotracheal intubation
- Needle cricothyrotomy
- Transtracheal jet insufflation
- Tracheal suctioning
- Orogastric and nasogastric tubes
- Decompress chest with needle
- Establish/monitor peripheral IV (extremities)
- Establish/monitor heparin lock
- Establish/monitor intraosseous infusion
- Establish/monitor internal jugular vein lines
- Establish/monitor external jugular vein lines
- Establish/monitor central venous lines
- Infuse IV fluids (all)
- Collect blood samples
- Administer Medications by standing orders
- Administer/monitor IV drip medications
- Monitor blood/blood by-products

Source: Colorado State Board for EMT Certification

Sustainment of SOCM Medical Skills

Refresher training is provided for 2 weeks every 2 years through the Special Operations Skills Sustainment Program (SOFMSSP). This training provides revalidation of skills and credentialing at the EMT-P level.

Overview of SOCM skills training

The Joint Special Operations Medical Training Center trains Special Operations medics in a variety of invasive and surgical procedures. These medics represent what is believed to be the future of many combat medics in the military, incorporating surgical procedures in their array of medical treatment capabilities.

The following information has been adapted from the Surgical Procedures (Trauma) used in the training of Special Operations Combat Medics, and from other sources.

Wound Management and Repair

These procedures involve the use of suturing for repairing wounds of various kinds, and involve cognitive choices such as choice of appropriate sutures and motor skills such as suturing technique. The methods include wound recognition and application of local anesthetics.

Objectives: Following training, the student will be able to:

- State the mechanism(s) of injury that cause lacerations and impact on management and healing
- Describe the when/why suturing is indicated or not indicated
- List important historical items
- Describe what to look for during examination of a wound
- List the various sutures and suture needle type and indications for using each type
- List the common surgical instruments used in suturing and describe how each is properly used
- List the different types and concentrations anesthetics that are commonly used during suturing
- State the maximum dose, indications, contraindications and side effects of each common anesthetic
- List the different ways in which the common local anesthetics can be used
- Demonstrate proper wound prep and proper surgical technique

Reasons for Suturing:

- Cosmetic
- Decreased healing time
- Wound protection
- Hemostasis

Reasons for Not Suturing:

- If no improvement in cosmesis expected
- Dirty/grossly contaminated wound or old injury
- Animal bite
- Patient refuses

Needle Jet Insufflation Airway (Needle cricothyroidotomy)

Insertion of a needle through the cricothyriod membrane or into the trachea is a useful technique in a variety of situations. It is available on a short-term basis until a definitive airway can be established. Jet insufflation can provide temporary, supplemental oxygenation so that intubation can be accomplished on an urgent rather emergent basis. Knowledge of the neck and upper airway structures is imperative to performing this procedure. The anatomical landmarks include the hyoid bone, the thyroid cartilage, the cricoid cartilage and the tracheal rings. The ventilation approach uses either pressurized O2 supply or bag valve devices.

Surgical Cricothyroidotomy

Surgical cricothyroidotomy is performed by making a skin incision that extends through the cricoid membrane. A curved hemostat may be inserted to dilate the opening, and a small endo-tracheal tube or thoracostomy tube (preferably 5-7 mm) can be inserted. One must be alert to the danger that the ET tube can be mal-positioned by inserting too deeply, placing the tube into the right main stem bronchus. Care must be taken, especially in children, to avoid damage to the cricoid cartilage, which is the only circumferential support to the trachea. Knowledge of the neck and upper airway structures is imperative to performing this procedure. The anatomical landmarks include the hyoid bone, the thyroid cartilage, the cricoid cartilage, and the tracheal rings.

Tubal Thoracostomy

This technique is for rapid decompression of tension pneumothorax and respiratory management of patients with hemothorax or pleural effusion. It can be used to prevent simple or potential pneumothorax from developing into tension pneumothorax when positive pressure ventilation is required, and to evacuate and assess the severity of intrathoracic hemorrhage.

Indications:

(1) Rapid decompression of tension pneumothorax.
(2) Prevent simple or potential pneumothorax from developing into tension pneumothorax

Steps:

(1) Inject anesthetic into skin if patients' condition permits.
(2) Make a 2-3 cm incision just anterior to the mid-axillary line overlying the rib. Continue the incision into the subcutaneous tissue.
(3) With a Kelly clamp, the dissection is carried over the fifth rib and into the fourth intercostal space through the intercostal muscles, and with a sharp, thrusting

when positive pressure ventilation is required.

(3) Evacuate and assess the severity of intrathoracic hemorrhage.

motion the pleura is penetrated.

(4) Widen the hole by expanding the clamp.

(5) Insert a gloved finger into the hole to ensure that: (a) the pleural cavity, and not the abdominal cavity, has been entered, (b) no intra-abdominal organs are in the way of the chest tube, and (c) that the lung has not adhered to the lateral pleural walls.

(6) Withdraw the fingers, and insert the tube into the thoracic cavity, guided by the Kelly clamp and then directed upward toward the apex of the thoracic cavity.

(7) Immediately connect the chest tube to suction to evacuate the pleural cavity and re-expand the lung.

Needle Thoracentesis

This procedure is used for the rapidly deteriorating critical patient who has a life-threatening tension pneumothorax. Care must be taken – if the patient does not have a pneumothorax, there is a potential for creating a pneumothorax or damaging the lung. The procedure involves the insertion of a needle through usually the 2nd intercostal space, midclavicular line on the affected side. This is followed by evaluation of relief of the tension pneumothorax and preparation for chest tube insertion.

Venous Cutdown

This procedure is used when rapid access is required to the vascular system, and less invasive approaches are not possible. It is used in cases such as severe burns. Anatomical localization must be accurate and precise, involving incision, dissection and cannulation of the of the vein. Veins in the upper and lower extremity may be used, including the greater saphenous vein or the basilic vein.

Control of Hemorrhage by Vessel Ligation

This procedure is used when hemorrhage needs to be controlled, but circumstances prohibit normal methods such as direct pressure or packing combined with elevation, such as urgent multi-system trauma, the possibility of hematoma formation hampering wound closure or when the location of the hemorrhage may interfere with the airway or the cerebral circulation. The procedure involves placement of a surgical ligature around the artery and tying off using a knot.

Escharotomy

This procedure when full thickness burns prevent respiratory movement or circulation in an extremity. It involves incisions along the eschar, in the lateral/medial lines of the chest or limbs to include the joints.

3. Trauma Skills Training for Physicians

Physicians and surgeons comprise a relatively small portion of active-duty medical personnel in the military. However, they have a key role in maintaining a healthy fit force. This role varies substantially from civilian medical practice and exhibits variations between the Army, Navy and Air Force and by location of deployment and nature of mission. Important areas of differences include: infectious diseases not commonly seen in civilian practice in the United States, extremes of climate or depravation, and missions other than war. Because of its very nature, care of Army, Navy, Marine or Air Force personnel injured in combat remains a high profile and critically important element of military medical care.

Injury exacts its toll in life within minutes and the first hours of impact on the human body. Thus, the medic, physician and surgeon engaged in combat trauma care must be ready and able to provide that care without access to other support resources. There is no time for consultation- skill and knowledge are needed at that instance to intervene to save life and limb and to minimize morbidity of wounded soldiers. Accountability for the quality of care rendered to the combatant is a major burden for military medical corps.

Training and sustainment of military medical personnel relies heavily on United States civilian standards. All military training programs seek to expose their trainees to civilian injured patients since few injured patients are treated in military hospitals in the United States. Over the past two decades, arrangements have been made with urban civilian training programs. Specific civilian courses that are available to military medical personnel include:

- Advanced Trauma Life Support Course (ATLS). This course was developed by the American College of Surgeons to train physicians in a routine for treating patients with severe injuries. The course emphasizes the first hour of initial assessment and primary management of injured patients starting at the point of time of injury and continuing through initial assessment, life-saving intervention, re-evaluation, stabilization and when needed, transfer to a facility in which the patient can received specialized care such as a "trauma center".

- Definitive Surgery for Trauma Care Course. This course is a technical surgical course that was developed to pick-up where the ATLS course stops and specifically focuses on surgical maneuvers that would be required of a surgeon in a life-threatening trauma situation and for which practice during a standard training program is not consistently or readily available. This course is now offered throughout the world and has been offered a number of times through the Uniformed Services University of the Health Sciences to U.S. surgical trainees.

There is a general concern in military services throughout the world about adequate preparedness for trauma care in a combat environment. Some of this can be addressed by intensive focus on training for trauma care in a civilian environment. However, this cannot adequately address the special needs of the military.

Differences between civilian trauma care in the United States and combat trauma care include the following:

- Wounding agents are different. In combat, the wounding agents are high velocity projectiles or combination injuries, e.g., combination crush, burn, blast as well as penetrating trauma. It is unusual to develop skills on this particular set of patients in a civilian environment and some injuries are impossible to replicate, e.g., mine injuries.

- The tactical environment places substantial impediments on delivery of care at the point of wounding. There is a substantial risk to care providers. Thus, accurately identifying care that is needed is particularly important. For instance, in the civilian environment intravenous lines are often established with little or no indication. Transportation of this code of behavior to the tactical military environment places caregivers at risk, further prejudicing mission success.

- The military environment has long delayed evacuation times with differing pathophysiological presentations to definitive caregivers.

- There is increase reliance on care at the point of wounding and the medics must have higher skills and be surer of their care capabilities then civilian counterparts.

- Resource constraints for the continuum of care. The resource constraints in the tactical environment include not only supplies such as blood and operating rooms, but also access to specialty advice and guidance from neurosurgeons and other specialists, which are easily accessible in the civilian environment.

- Continuum of care in the military environment. Because patients must be transported from the combat zone to areas of safety sequence of caregivers must be involved in patient care. This places a greater reliance on communication and means that procedures should, whenever possible, be standardized to minimize complications and impact miss-communications.

The military medical patient population is, however, younger, fitter and more able to overcome the stresses associated with injury than the civilian population. Whereas, this is a potential benefit to the military, it also means that a lot of research and training focus in the civilian area is miss-applied and lacking in relevance to the military environment. For instance, multiple organ failure is a complication of severe injuries in the civilian environment, but it is rarely found in fit young persons surviving an episode of injury.

The very special needs of military combat trauma training requires a major focus to bridge the ever-increasing gap between textbook and the requirements of field combat trauma care. Increasing the civilian training programs in the United States rely on minimal access surgery in high technology tertiary care multidisciplinary environments. None of these elements is present in combat. Thus, although military trainees are exposed to severely

injured patients in urban trauma centers, their training needs differ substantially from their civilian counterparts.

Modern doctrines of disperse low intensity warfare means that there will be no learning curve. There will, however, be continued accountability for quality practice of medical care in the combat zone. If there ever was an opportunity for simulation to establish added value, it is in the application to training and sustainment of preparedness for combat trauma care.

D. Review of Medical Simulation in the Civilian and Military Sectors

1. Overview of Medical Simulation

The availability of fast graphics computers, sensory interfaces that convey the sensation of 'touch and feel' to the user, and accurate anatomical models have enabled the development of simulators for medical applications. This technology, also known as 'surgical simulation', can provide an environment in which to train and credential healthcare personnel, evaluate medical devices and new therapies, and plan interventional and surgical procedures using patient-specific data.

Medical simulation has been identified in the 'Joint Science and Technology Plan for Telemedicine' (Armed Services Bureau, 1997) as a primary approach for increasing individual medical skills proficiency in trauma in the military. Different systems support different levels of visualization, including viewing of 3D models on a two dimensional (2D) computer monitor, immersive 3D visualization using stereoscopic glasses, and 3D holographic displays. Interactivity can range from fly-through navigation using a passive endoscopic interface to manipulation of deformable tissues using a haptics ("touch") interface. These simulators allow the user to interact with computer-generated 3D models of human anatomy, and can provide effective trainers for learning the dexterous skills associated with trauma procedures such as chest tube insertion and IV placement. This technology can not only support procedural training and skills testing, but can also provide a realistic reproduction of stressors associated with the combat environment.

DoD uses computer graphics, 3D modeling and simulation for a variety of purposes, such as to train individual soldiers, conduct joint training operations, develop doctrine and tactics, formulate operational plans, assess war-fighting situations, evaluate new or upgraded systems, and analyze alternative force structures. The technology also supports the requirements of other critical defense needs such as command, control, and communications; computing and software; electronics; manpower, personnel, and training; and manufacturing technology. As a result of this breadth, defense models and simulations range in size and scope from components of large weapons systems through system-level and engagement-level simulations, to simulations of missions and battles, and theater-level campaigns. DOD's modeling and simulation activities, such as SIMNET and the 73 Easting simulation, have helped the services get away from major field exercises that required the agency to move large numbers of people around. In the future, DOD hopes to use modeling and simulation to provide readily available, operationally valid environments for use by all DOD components. It would like users to have daily access to war-fighting scenarios from their offices, in the same places that they normally work.

Similar approaches can be used for the development of medical simulators that can prepare the combat medic, surgeon and other personnel for mass casualty scenarios and the delivery of medical care in the far forward environment. Specific emphasis can be placed both on individual training and on team training. Dexterous skill-based simulators using technologies such as the virtual workbench can train skills proficiency can be used by students and experienced personnel to practice existing and emerging trauma procedures in

a local setting. Larger virtual environment technologies can be incorporated into simulation centers to provide individuals and team members with an immersive experience that emulates combat conditions. These computer graphics systems can also be integrated into existing DoD simulation systems and linked to combat databases, to provide scenario-based training and cohesion with other military simulators.

DARPA Funded Development of Surgical Simulators in the 1990's

A major portion of the budget of the Advanced Biomedical Technology (ABT) program of the Defense Advanced Research Projects Agency (DARPA), under the guidance of Dr. Richard Satava, has been devoted to the development of surgical training simulators over the past several years. This program was very successful in providing funding for the development of new applications in medical simulation for training healthcare personnel, especially for interventional and surgical simulation. Figure #19 provides an overview of recent projects in this area funded by the ABT program of DARPA. Although the program 'jump-started' many projects in medical simulation, the commercial markets in medical simulation have not yet materialized, so subsequent commercialization of this surgical simulation technology has not been successful.

Figure #19: 1999 Overview and Status of Medical Simulation Projects funded by DARPA

Project	Description	Company	Status
Virtual Anastomosis	Virtual workbench application for assessment of surgical skill	Boston Dynamics (BDI)	Commercialization
Surgical Metrics	Committee of surgeons for development of metrics and virtual workbench for assessment of surgical skill	Image Medical	Phase II STTR grant, initiated January 1999
Virtual Endoscopy	Patient-specific virtual endoscopy application for preoperative planning	GE Medical Systems	Commercialization
Virtual Laparotomy	Virtual environment for training in the exploration of abdominal trauma	HT Medical Systems	Project ended, no product
Virtual Limb Trauma	Virtual environment for management of limb trauma	Musculographics	Commercialization failed

Note: Data derived from the 'Medicine Meets Virtual Reality' Meeting, January 1999.

Types of Medical Simulators

There are two general classes of computer-based simulators that have been developed for training in medical skills and procedures. The first includes mannequins that exhibit appropriate physiologic responses, and which can be manipulated for training in anesthesiology, obstetrics and gynecology, or emergency life-saving procedures. Examples of this type of system are the training simulators that have been developed by MedSim and METI for anesthesiology residency training. Although this systems have training value for certain procedures and skills, they do not alone offer the broad flexibility offered by virtual reality technology, and they do not provide an immersive experience that has been shown to be important for effective training in other military domains.

A second type of medical simulator is based on so-called 'virtual reality' technology. A VR medical simulator contains a computer-generated 3D model of anatomy at its core. The user can interact with the model in real-time, and simulators generally provide visual and haptic ("touch") immersion. Different systems support different levels of visualization, including viewing of 3D models on a 2D computer monitor, immersive 3D visualization using stereoscopic glasses, and 3D holographic displays. Interactivity can range from fly-through navigation using a passive endoscopic interface to manipulation of deformable tissues using a haptics interface.

Figure #20 provides an overview of the components of a surgical simulation system. The core of the system is the 3D anatomical dataset that can be manipulated by the user. All of the user interactions with this dataset must be modeled in the virtual environment, including tracking of instruments in 3D space, deformation and reactions of the anatomical model to manipulation by the user, and transmission of visual and haptic sensation to the user. In addition to the input and output (I/O) functions of the system, other components may include training and educational features, performance assessment software and links to databases and other calls.

Surgical simulation requires the fastest graphics processing, which have typically been provided by high-end UNIX-based workstations supplied by Silicon Graphics, Inc. The high level of interactivity provided by the system requires complex integration and synchronization of the components. Often the haptics interface will be supported by a separate computer that must then be integrated in real time with the rest of the simulation.

The most commonly used haptics interface is the PHANToM made by SensABLE Technologies, which provides force feedback to the user. The primary source of stereoscopic glasses is CrystalEyes, available from Stereographics. Tracking can be mediated by electromagnets, optics, sound, and other modalities, but the most commonly used trackers are magnetic systems are provided by Polhemus. Head-mounted displays are made by a variety of manufacturers, but are not as commonly used for surgical simulation as they are for military and flight VR applications.

Figure #20: Components of a Surgical Simulation System

- *Graphics computer:* The CPU must be powerful enough to manipulate large, complex 3D models in real-time (defined as 30 frames per second or greater).

- *3D models of anatomy and medical devices*: A 3D dataset is needed for the graphics model. Sources of anatomy include the Visible Male and Visible Female datasets, as well as MRI, CT and US data from patients. Models also allow the user to visualize surgical instruments in the context of the virtual environment.

- *Visual display:* These can include a standard computer monitor, stereoscopic glasses for viewing the simulation in 3D, and other visual displays.

- *Haptics display:* A haptics device may be needed as an interface between the simulation user and the graphical model to transmit realistic tactile and/or proprioceptive forces (force-feedback). These can range from relatively simple catheters or endoscopes that provide resistance, to complex glove or exoskeletons interfaces that attempt to reproduce some properties of the human hand.

- *Tracking device:* Electromagnetic systems have generally been used to track the 3D position of the simulation user and instruments in the virtual environment.

- *Head-mounted display (HMD):* Immersion in the virtual environment may be enhanced by wearing an HMD.

- *Virtual workbench:* Mirror-based system can use active stereoscopy so that user has enhanced 3D sense of interaction with virtual environment.

- *Holographic display*: Holography for creating a highly realistic 3D image of the virtual environment.

- *Extended virtual environment (eg, CAVE):* For some applications the sense of realism may be enhanced by the addition of noise, wind, etc. in the external environment.

- *Other sensory displays:* Audio display may increase presence and realism; and olfactory displays may increase realism, as will temperature.

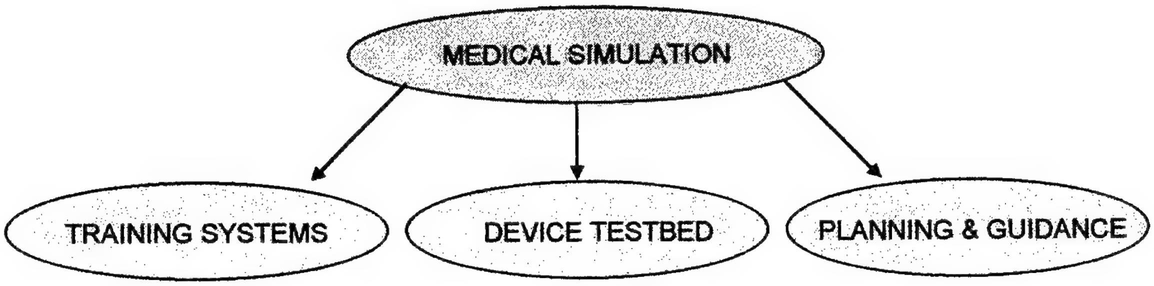
- *Mannequins, props*: In some cases it may be necessary to provide a physical model of a limb or other body compartment as a 'front-end' to the simulation system. Examples include arm models for intravenous insertion, trocars placed in an abdominal model for laparascopic procedures, head and neck models for surgical management of airway function, etc.

- *Performance tracking software*: Used for assessing user performance and skills.

- *Other components:* Interface control software and hardware, and software for synchronization and control of the simulation.

Medical Simulation Applications

Medical simulation can have several applications. These include systems for training and accreditation of surgeons and other medical personnel, test-beds for the design and analysis of new therapies and devices, and platforms for surgical planning.



What Can and Cannot be Effectively Simulated in Medicine

The following are examples of procedures, skills, physiological systems, models and other phenomena that can or cannot be effectively reproduced give the current state-of-the-art. This is not an exhaustive list - it merely highlights limitations of the current technology.

Can Effectively be Simulated in Real Time (approximately 30 frames per second):

- Minimally-invasive procedures, where the user manipulates a device at-a-distance
- Instrument-based procedures, such as suturing, grasping and cutting, with moderate fidelity
- Surgical skills trainers, using part task training for procedural applications
- Introduction and use of new medical devices and new medical procedures – training the user in placement and manipulation of new devices
- Simulation of respiration and lung movement
- Simple tissue deformation and responses to user intervention

Cannot be Effectively Simulated Given Current Technology:

- High fidelity simulation of open surgical procedures where the operator's hand is an integral part of the procedure
- Whole task training on complex procedures where the goal is to completely suspend disbelief on the part of the user (highest fidelity, greatest realism)
- Simulation of complex cardio-respiratory function
- High fidelity simulation of cutting and bleeding
- Complex movement of deformable organs, such as those found in the abdomen
- Procedures requiring high force or force feedback, (e.g., external fixation, blunt penetration of chest wall) because of limitations in haptics devices.

2. Medical Simulation Training Efforts in the Civilian Sector

There are a number of commercial and university-based efforts underway to develop medical simulation trainers. This section provides a brief overview of the current state of medical simulation products, university-based research in modeling and simulation, and skills trainers.

(A) Commercial Systems and Products

As stated above, there are two general classes of computer-based simulator products that have been developed for training in medical skills and procedures. The first includes computer-based mannequins that provide the user with physiological feedback and a physical substrate for inserting instruments. The second are computer graphics and virtual reality systems that allow the user to interact with a three dimensional (3D) model of computerized anatomy. These systems have largely been configured for training in minimally invasive procedures, or as general platforms that can support virtual medical applications. Many of these small commercial ventures have used grants and contracts from the DoD to help fund medical simulation research and development. An overview of these commercial simulation products is shown in Figure #22.

Figure #22: Examples of Medical Simulation Training Products

Product	Company	Application
Knee Arthroscopy Trainer	Boston Dynamics, Inc.	Procedural training in arthroscopy
Virtual Surgery Trainer	Boston Dynamics, Inc.	Basic skills training in vascular anastomosis
Reality Sculptor	Ciemed Technologies, Inc.	Basic skills training in trauma and surgery
CathSim	HT Medical Systems, Inc.	Basic skills training in needle insertion
PreOp Endoscopic Simulator	HT Medical Systems, Inc.	Procedural training in bronchoscopy
PatientSim	Medsim, Inc.	Mannequin for training in anesthesiology and allied health
UltraSim	MedSim, Inc.	Basic skills training in ultrasound
PediaSim	METI	Mannequin for training in pediatrics
Human Patient Simulator	METI	Mannequin for training in anesthesiology and allied health
Limb Trauma Simulator	Musculographics, Inc.	Procedural training in wound repair
MIST (Minimally Invasive Surgery Trainer)	Virtual Presence, Ltd.	Basic skills training in laparoscopy

Civilian Markets for Medical Simulation

The civilian markets for medical simulation trainers have not yet materialized, and this has hampered technology development. In flight simulation, which is often used as a paradigm for medical simulation, widespread adoption of simulation trainers did not occur until the military and the Federal Aviation Administration mandated use of these systems. In medicine, it is expected that broad adoption of medical simulation may depend on a number of factors. First, there must be both economic and quality of care incentives to change the current mentor-apprenticeship training environment of residency programs, now characterized by practice on patients and the "see one, do one, teach one" approach. This may occur as residency training is moved to the private sector, younger computer-literate physicians move into senior positions of responsibility, and professional organizations and influential individual physicians champion the use of simulation technology for training and performance assessment. An integral part of this process will be clinical validation of the efficacy of simulation-based training, including the development of performance metrics, published studies comparing the utility of traditional training with simulation-based training, and "pioneer" programs in the military and elsewhere that can provide early testimonial to the benefits of simulation training. Second, the technology must improve to support a more realistic simulation environment, including photo-realistic graphics, high-resolution haptics, and real-time rendering of large anatomical datasets. This will occur as university R&D efforts, such as the NSF Engineering Research Center based at Johns Hopkins, are funded to develop cutting-edge technologies in modeling, robotics and simulation.

Although the current civilian markets for medical simulation have not yet emerged, there is expected to be tremendous commercial potential in this technology within the next 5-10 years. This field will gain from changes in the healthcare marketplace which emphasize quality of care and error reduction, the explosion of the post-secondary education and training marketplace based on distance learning and automated performance assessment, and the increasing dependence of medicine on computers for training, administration, diagnosis and treatment.

Errors in Medicine

The health care practitioner (*e.g.*, physicians, medics) is often blamed for adverse events and adverse patient outcomes. A recent report from the Institute of Medicine has also highlighted the impact of medical errors on patient morbidity and mortality. Computer-based simulation has been used extensively in the airline industry and military for training cognitive, perceptual and cognitive skills. Although there are significant differences between flight and medical training, one common advantage offered by simulation in both arenas is the ability to expose personnel to unusual settings and situations where practice improves performance and reduces error in real world tasks. In flight simulation, pilots are exposed to dangerous scenarios such as broken engines, difficult settings such as night landings on aircraft carriers, and unusual situations such as treetop flight, all of which would be difficult or impossible to perform in the real world without repeated prior exposure on a simulator (Higgins et al, 1997).

Procedural Trainers

A number of small companies are developing simulators that can be used for training in specific interventional and surgical procedures. These range from simple insertion of a hypodermic needle into the veins of the arm, to complex 3D virtual workbench systems that reproduce many aspects of invasive neurosurgical procedures. At the low end of the spectrum, these computer-based simulators compete with training on simple plastic models and mannequins and media such as textbooks and CD-ROMs, and must be priced accordingly.

There is a learning curve associated with all medical procedures, with increased error rates occurring during the first 10-100 times a new procedure is performed, and errors are most often associated with junior doctors and physicians in training. Procedural training simulators offer the ability to train on virtual patients without harming actual patients. The first focus of companies developing procedural simulators has been so-called "low-hanging fruit", which are procedures that are performed many times by a large number of practitioners.

Several products are being developed to address the emerging market in the military and civilian sectors for trauma training and emergency medicine. These include instrument-based procedural simulators developed for nursing and allied health, mannequin trainers and sophisticated virtual workbench-based systems. Examples include simulators developed for intravenous (IV) line placement, chest tube insertion and airway management, including CathSim (HT Medical) and the Pre-Hospital Human Patient Simulator (Medical Education Technologies, Inc.) for nurse, medic and corpsmen training.

Human Mannequin Trainers

The human patient anesthesiology simulation systems are mannequins that contain openings for the insertion of instruments such as hypodermic needles, chest tubes, venous lines and airway management devices. They provide physiologic feedback and respond to application of drugs and other manipulations with responses that include heart sounds, breath sounds, simulated lung mechanics, blood pressure, electrocardiogram (EKG), and other characteristics of a human patient. They do not contain computer graphics models of anatomy and do not provide the user with an immersive VR experience. These mannequin systems were originally developed for training residents in anesthesiology. Several residency-training programs now mandate that residents train and be certified on these mannequins.

There are two companies that sell mannequin-based systems: MedSim, Inc. and Medical Education Technologies, Inc (METI). The MedSim product is called PatientSim and the METI product is called the Human Patient Simulator. MedSim recently acquired this product by merging with Eagle Simulation, a spin-off of CAE-Link, the large flight simulation company. METI was a spin-off of Loral / Lockheed Martin, the defense contractor.

Virtual Endoscopy

The most successful commercial medical VR products to date are virtual endoscopy simulators, including the Navigator (GE Medical Systems) and 3D Virtuoso (Siemens) systems. These systems use preoperative MR or CT images to construct 3D flythroughs or single views that simulate the experience of endoscopy using the patient's dataset. Navigation is driven either by mouse clicks on a simulated endoscopic view, or by manipulating the 2D image planes. Applications have included bronchoscopy, colonoscopy, gastroscopy and ureteroscopy, as well as fly-throughs of the vasculature and the ventricular system of the CNS. Currently there are some limitations to this technology, for example, the fly-through endoscopic renderings may take a long time depending on available computer processing power, and it is still not possible to view multiple datasets at once and identify pathological tissues by differential coloring.

Assessment of Medical Simulation Products by Trauma Surgeons

A committee of trauma surgeons and other clinicians evaluated medical simulation products under the auspices of the DARPA Phase II STTR project entitled "Surgical Simulation for Combat Trauma Training". The simulators examined in this study are shown in Figure #23. The goal of the analysis was not primarily to gather subjective impressions about the quality, realism and suitability of individual simulator products, but rather to assay the current state of surgical simulator technology and develop recommendations for continuing research and development efforts. This information was used to guide selection of appropriate simulation training instruments to conduct training efficacy analysis using performance metrics.

The committee saw medical simulators as a potentially beneficial tool for teaching both rudimentary surgical skills and complex trauma surgical procedures that incorporate both decision-making and psycho-motor skills. General recommendations of the committee included:

- Establish a "User-Centered Design Team" to ensure direction toward the end-user as well as technology
- Formulate a stepwise incremental approach to aggregated tasks (i.e. procedures)
- Incorporate haptics into the simulators (i.e. finger pinch, grip)
- Establish a multidisciplinary design team to work with the American College of Surgeons Committee on Trauma Chairman to focus on ATLS procedures

Specific feedback from the committee included:

- The computer graphics component (virtual environments and modeling) of commercial products offered to date was of sufficiently poor quality to deter adoption of these products for surgical training. The surgeons felt that, given the

Figure #23: Medical Simulation Products and Prototypes Examined by Trauma Surgeons

Simulator	Vendor	Components	Features[b]	Applications
Virtual Anastomoses Trainer	Boston Dynamics, Inc. (BDI)	• console workbench • mirror • stereoscopic glasses • audio • PHANToM interface • graphics computer	• real-time force feedback • physics-based simulation • skill assessment • flexible parametric tubes • reconfigurable organs • 3D graphics and sound	• virtual anastomosis • virtual aircraft maintenance • haptic cartography
Reach-In 3D Virtual Workbench	CieMed[c]	• console workbench • mirror • stereoscopic glasses • PHANToM interface • graphics computer	• real-time force feedback • physics-based simulation • 3D graphics	• neurosurgery planning • industrial design
CathSim	HT Medical, Inc.	• needle insertion tactile interface • graphics computer	• real-time force feedback • physic-based simulation • skill assessment • patient case studies • 3D graphics	• needle insertion • PICC • central venous line placement
PreOp Endoscopic Simulator	HT Medical, Inc.	• endoscopic interface • mannequin • graphics computer	• real-time navigation • patient case studies • skills assessment	• bronchoscopy • neuroendoscopy • flexible ureteroscopy
Limb Trauma Simulator	Musculographics, Inc.	• workbench console • stereoscopic glasses • PHANToM interface • virtual surgical tools	• real-time force feedback • physic-based simulation • 3D graphics	• trauma training

[a] –Based on surgcial and/or engineering analyses., [b] -Based on direct evaluation and vendor's literature.

capabilities of other computer graphics work that they had observed in other domains (eg, movies, entertainment), that this component of surgical simulation could be substantially improved given the current state of this technology.

- Simulation training stations are required to be "in context", ie., involve specific decisions and an assessment of user decision skills under stress.

- Commercial products that have been developed to date, including the 'CathSim' IV insertion trainer from HT Medical, Inc., and the 'Limb Trauma Simulator' from Musculographics, Inc., were clearly being developed without sufficient interface between technologists/engineers and the physician end-user. Products incorporating 3D virtual workbench technology providing the most realistic approach to surgical simulation. These included the 'Surgical Simulator' workstation from Boston Dynamics, Inc. (BDI). Although this system presented a somewhat rudimentary approach to performance metrics, it provided a promising platform for further development.

- Completely realistic hand-based haptics interfaces were some probably 5-10 years away from realization.

One of the ongoing tasks of the committee was to begin the development of surgical performance metrics to be developed in conjunction with the American College of Surgeons. Near term goals were to guide the development of surgical simulation technologies to supplant animal models in trauma training. The committee will specifically address the potential for the use of surgical simulation as an animal replacement in the skill stations required for the Advanced Trauma Life Support (ATLS) course offered by the American College of Surgeons.

<u>Identification and Prioritization of Procedures for Trauma Skills Training</u>

The first objective was to identify trauma skills and procedures that are both highly relevant to the pre-hospital (eg, combat medic) and hospital (eg, trauma surgeon) worker, and determine which of these are well suited to training using simulation technology. Figure #3 shows the results of a preliminary survey of the User-Centered Design team on the relevance of specific procedures. The list of prioritized procedures was identified based on discussion and voting by members of the design team. These included:

1. Chest tube insertion, needle thoracentesis
2. Cricothyroidotomy
3. Hemorrhage control
4. Intravenous needle and line placement

Next, these procedures were evaluated for feasibility of implementation within the simulation environment. Several issues emerged from this analysis. Procedures such as vascular and respiratory access that depend largely on instrument handling are easiest to implement using simulation technology because they require limited haptics feedback and

relatively constrained motion. In contrast, open procedures such as treatment of hemorrhage may have a great training need, but may be impossible to implement given the current state of the technology. Figure #23 shows the results of the product evaluation by the committee (Identified by the consensus workshop, "Technical Skills Metrics and Medical Simulation Priorities", USUHS, Bethesda, MD, July 1999, Supported by the Defense Advanced Research Projects Agency (DARPA)).

Figure #23. Initial evaluation of procedures for simulation training in trauma

Procedure / skill	Prehospital relevance	Hospital relevance	Feasibility for Simulator Development	Existing Training Simulator(s)
Peripheral I.V. line placement	High	Moderate	Moderate – training available using other approaches	CathSim IV trainer (HT Medical, Inc.); also mannequins
Subclavian central venous placement (CVP)	Low	High	Moderate	Practice mostly on patients
Venous cut down	Moderate	Moderate	Moderate to difficult	None; practice mostly on patients
Needle thoracentesis	Low	Moderate	Moderate	Mannequins available for training
Chest tube insertion	Low	High	Difficult	Mannequins available for training
Surgical airway	High	Moderate	Poor- difficult to simulate	Practice mostly on patients / animals
Major wound hemorrhage	High	High	Poor- difficult to simulate	Limb trauma trainer (Musculographics, Inc.)
Lumbar puncture	Low	Moderate	Excellent – easy to simulate	Academic prototypes available
Abdominal lavage (paracentesis)	Low	High	Poor- difficult to simulate	None; practice mostly on patients
Basic suturing skills	Low	Moderate	Moderate	Virtual anastomosis trainer (Boston Dynamics, Inc.)

Other possible skills/procedures identified by the team:

- Thoracic injury evaluation trainer
- Intraosseus infusion
- Soft tissue debridement
- Ultrasound simulation

(B) University-based Research in Medical Modeling and Simulation

There are a number of academic efforts that are conducting research and development in medical modeling and simulation that are essential for providing the core technology for future medical training applications in the military (Figure #24). Some of these efforts are cross-disciplinary, involving departments of Biomedical Engineering, Computer Science and medical school departments such as Surgery and Radiology. Funding for this research and development has come from a variety of public sources, including the Advanced Biomedical Technology program of the Defense Advanced Research Projects Agency (DARPA), National Aeronautics and Space Administration (NASA), National Institutes of Health (NIH) including the National Library of Medicine, National Science Foundation (NSF), the U.S. Army Telemedicine and Advanced Technology Research Center (TATRC), Naval Medical Research and Development Command and the Whitaker Foundation. Examples of recently established cross-disciplinary programs include the NSF Engineering Research Center (ERC) at Johns Hopkins, CIMIT, and the new "Bio-X" Biomedical Engineering initiative at Stanford University.

The legacy of DoD funding of university-based research in medical modeling and simulation has been one of extraordinary technology development, often with little consequence for the military end-user. This research has appropriately focused on basic research in computer graphics, biomedical engineering, mathematical modeling and haptics, with application areas addressing the needs of academic clinicians, including minimally-invasive therapies, image-guided surgery, diagnostic imaging, interventional techniques, and medical robotics. Although some of this research has applicability for emerging diagnostic and treatment modalities in trauma, few of these projects have relevance for training current trauma skills and procedures. Image-guided, minimally invasive procedures are not useful for the combat medic on the battlefield or the trauma surgeon in the forward surgical suite. Modeling and simulation research and development produces impressive results and engaging displays, but additional emphasis needs to be placed on the development of effective systems for training trauma personnel, including investment in more mundane and less quantifiable tasks such as user needs analysis, content development, instructional design and systems integration, as well as the simulation of trauma procedures such as chest tube insertion, treatment of wound hemorrhage and fracture repair.

Figure #24: Selected Examples of DoD-Funded Academic Research in Medical Modeling and Simulation

Institution(s)	Center	Examples of Application Areas
Harvard, MIT	Center for Innovative Minimally Invasive Therapy (CIMIT)	Minimally invasive surgery simulation
Cleveland Clinic	Computer Assisted Minimally Invasive Surgery Project (CAMIS) Project	Image-guided surgery
Georgetown University	Imaging Science & Information Systems Research Center	Medical robotics, image-guided surgery
Johns Hopkins, Carnegie Mellon University, MIT, Brigham and Women's Hospital (Harvard)	NSF Engineering Research Center, "Computer-Integrated Surgical Systems and Technology"	Medical robotics, minimally invasive surgery simulation
Massachusetts Institute of Technology	Artificial Intelligence Laboratory	Haptics for biomedicine
University of Colorado	Center for Human Simulation	Visible human project
University of North Carolina	Medical Image Display and Image Analysis Group (MIDAG)	Video guided laparoscopy, image fusion for radiotherapy
University of Pennsylvania	Center for Human Modeling and Simulation	Modeling of cardiac motion

3. Review of Current Efforts Using Medical Simulation in the Military

There are a number of "stove-pipe" technology development and implementation efforts using medical simulation to train healthcare personnel in the military. This section describes two examples where simulators are being used for training combat medics, physicians and other medical personnel.

Although these are admirable and impressive development efforts, there has been little attempt to integrate technologies into existing training programs. No efforts are being paid to match simulation technologies to skill requirements, or examine the efficacy of these training systems using the traditional human factors and instructional approaches that have been used in military simulation and commercial flight simulation.

The Integrated Research Team (IRT) for Medical Modeling & Simulation sponsored by the Telemedicine and Advanced Technology Research Center (TATRC) is addressing some of these problems through a more thorough review of current technology efforts, and design of a more integrated approach for training medical personnel using simulation.

(A) Combat Trauma Patient Simulation (CTPS) Program

The Combat Trauma Patient Simulation (CTPS) program is based on the development of trauma training functionality using the Human Patient Simulator developed by Medical Education Training, Inc. (METI). The program is congressionally funded, and the purpose is to more realistically assess the impact of battlefield casualties. The program has been managed by STRICOM, but is now being transitioned to the Telemedicine and Advanced Technology Research Center (TATRC) at Fort Detrick. The CTPS contains core components consisting of the Human Patient Simulator (METI), MILES Electronic Casualty Card, MEDREX virtual state model, Operational Research Casualty Assessment (ORCA) Model, and a communications network.

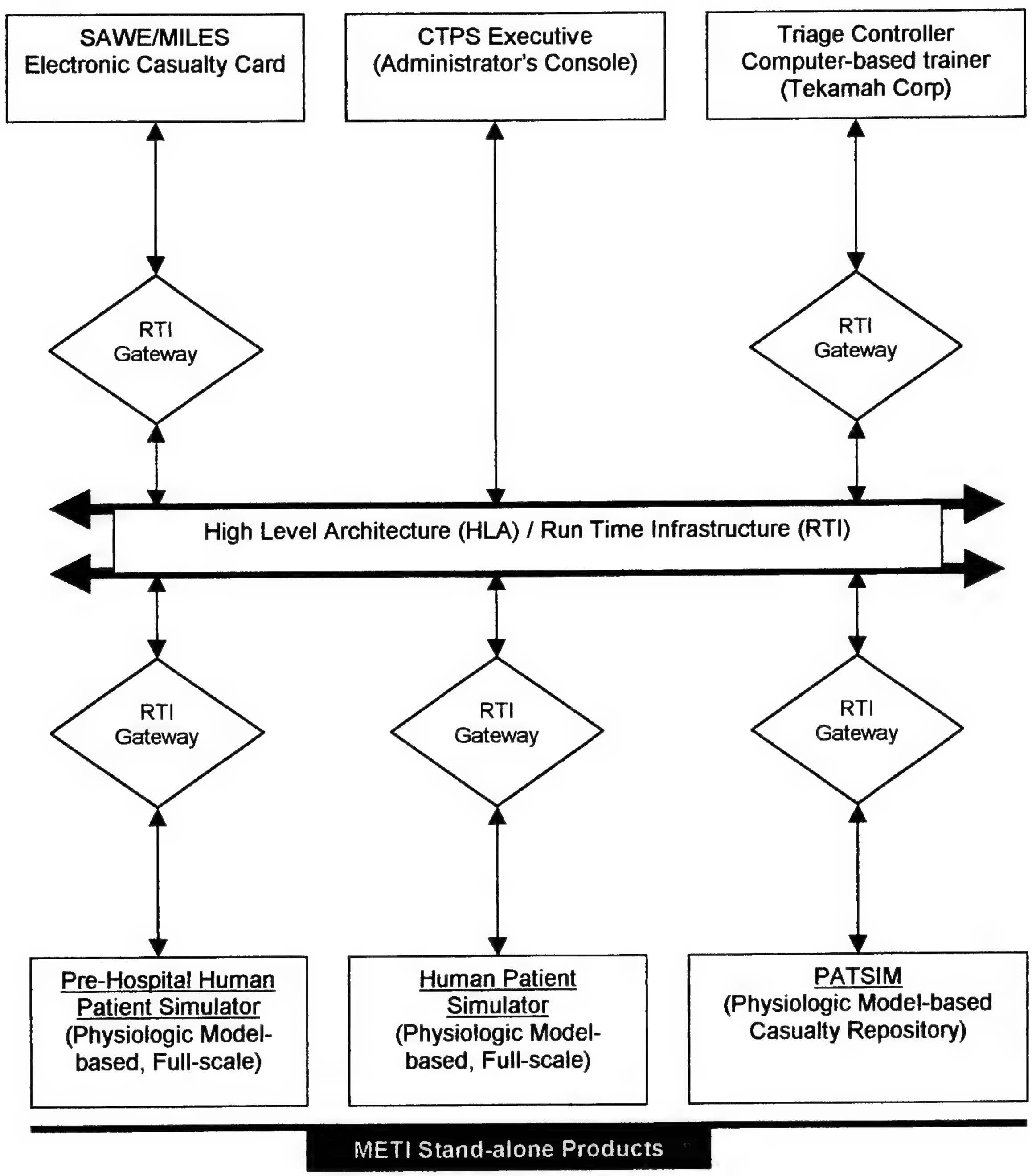
Budget:

Phase I of the CTPS program was initially funded in 1997, and Phase IV of the program is starting in 2000. Sources of funding include the following:

Source	**FY97**	**FY98**	**FY99**	**FY00**
DoD LFT&T	$800K	$1,200K	$600K	
Army Surgeon General		400K		
Army NGB		100K	60K	
STRICOM	85K	50K	60K	125K
SOCOM				260K
MRMC				$3,500K
Total	**$885K**	**$1,750K**	**$720K**	**$3,885K**

Proposed CTPS Network:

The CTPS network is designed to provide an integrated military medical system for training, test and evaluation, to more realistically assess the impact of battlefield casualties. The program leverages several common and government off-the-shelf (COTS and GOTS) products into an integrated system:



Progress and Future Plans:

Phase III - Current

During Phase III, a number of projects were initiated and some were completed. Among the tasks include development of:

Completed:

- Fully constituted military training scenarios, including landmine explosion, snake bite and pneumothorax
- Master control workstations and instructor/operator workstations
- ORCA integration
- MILES ECC integration
- Full HLA compliance with a 'plug and play' feature for other medical simulators

Not yet completed:

- A more 'hardened' mannequin for ground and air ambulance
- Wireless communications system
- Preliminary After Action Review (AAR) system capabilities
- Fully functional triage capability – PatSim (limited)
- Complete system integration software package (limited)
- Documentation

Other ongoing efforts include:

- Ongoing CTPS user assessments by STRICOM and METI
- Joint LSOMTC/STRICOM study on the required level of fidelity for medical mannequin type
- Initial studies on state-of-the-art for medical haptics

Phase IV

"The purpose of the Phase IV is to field a prototype CTPS system for training and test and evaluation bundled with the capability to demonstrate the application of CTPS for 91W initial, refresher and sustainment training. The fielding location is to be determined. The 91W training package need not be all inclusive; rather, it must demonstrate the capability of the CTPS system to be applied for this emerging training need. Note that this specific task does not mitigate medical instrumentation at the Combat Training Centers."

These core tasks were proposed by the developer for Year 4:

- Program and subcontract management
- System engineering
- Clean-up System 3 software

- Develop and implement casualty handling federate
- Analyze, develop and select additional medical information not currently supported by CTPS (focus on 91W/CLS training)
- Develop and implement After Action Review (AAR) federate for use with selected 91W/CLS training tasks
- Develop a CTPS based 91W/CLS training program
- Develop and implement a casualty generator
- Enhance FOM and federate RTI interfaces
- Enhance CTPS executive
- Maintain HLA certification
- Enhance database translator
- Develop a CTPS website for developmental collaboration

Integrated Product Team (IPT) recommendations: An IPT was developed jointly by STRICOM and USMRMC (TATRC) to guide further development of the CTPS and the transition to TATRC funding. The IPT met in May, 2000 and made recommendations to the company for improvement of the system.

Limitations of CTPS technology and problems with the CPTS mannequin

The CTPS has limited applications for trauma training, because a mannequin-based single simulator solution cannot all of the needs of the user for medical skills training. The user can only interact with a plastic mannequin, and cannot appropriately visualize the spatial relationships between trauma access techniques and the underlying anatomy. Because the system does not use immersive, virtual environment technologies, value-added features such as 3D performance tracking and stressful environmental characteristics are difficult to implement.

Problems have also been reported from military users of the CTPS. One of the biggest problems has been the amount of "down-time" reported by users, with simulators requiring more than expected amounts of maintenance.

(B) National Capital Area Medical Simulation Center

The National Capital Area Medical Simulation Center (NCAMSC) in Forest Glen, MD is a multi-functional facility that uses computer-based simulation to educate medical students, nurses, and resident physicians. The center arose as a partnership between the F. Edward Hébert School of Medicine (SOM), USUHS, and the Walter Reed Army Medical Center. The NCAMSC began operation in October, 1999 and consists of four discrete functional areas. These are: simulated patient clinic, telemedicine conference room, computer laboratory, and virtual reality lab with operating room. The NCAMSC is unique because it has these four functional areas under one roof. It is intended that the NCAMSC should become a resource for all medical training programs in the Washington, D.C. area, primarily military. It is hoped that the Center will provide an impetus and a site for the development and archiving of military medical databases for education and research.

Dr. Christoph Kaufmann is Director of the Surgical Simulation Laboratory. The Surgical Simulation Laboratory's mission is the development and utilization of computerized mannequin and virtual reality-based exercises for training and assessment. The Association of Military Surgeons of the United States (AMSUS) Virtual Reality Laboratory, a part of the Surgical Simulation Laboratory at the Center, is dedicated to the development of virtual reality simulations for clinical education and research. The laboratory consists of a control room flanked on one side by an operating room and on the other side by a virtual reality room. One-way mirrors permit supervision of these two rooms from the control room. The operating room is used to simulate a real operating room environment, initially for training and then eventually for testing as more realistic simulators are developed. A MedSim patient simulator mannequin will be used to train principles of physiology, anesthesia, and trauma care. This operating room is configured to be identical to a modern deployable (DEPMEDS) operating room. The VR room is a multipurpose room with adequate space either for several VR simulators to be used at once or for the entire room to become another operating room or to be used as a VR "theater" for a small group. The VR laboratory will also be used to assess the utility of existing VR technologies and products, suggest improvements, and integrate these products with each other.

The AMSUS Virtual Reality Laboratory has become a repository for medical simulation products and prototypes whose initial development was funded by DARPA's Advanced Biomedical Technology program. These include:

- <u>Telepresence Surgery System</u> (SRI International): The telepresence surgery system developed by SRI combines 3D video imaging, precise remote manipulation with handheld surgical instruments, and force feedback, to provide a realistic environment for remote surgical operation. The system was originally developed for remote surgery on wounded soldiers in the battlefield environment, but bandwidth requirements limited its use for real-time, remote surgical applications. The system consists of two modules, an Operator Module and a Worksite Module. The operator module provides a force-reflecting hand controller and a stereo display system with adjustable magnification. The worksite module contains a color monitor, a liquid-crystal shutter for stereographic viewing (the operator wears passive polarized glasses), a mirror to create a "virtual workspace" beneath the hand-operated master controller, stereo speakers, and the master, which is outfitted with a surgical instrument handle. The slave unit, or surgical manipulators, have interchangeable surgical end-effectors. Force feedback is provided on all axes of the manipulator, including the gripper squeeze force. Forces and torques generated as the tool touches objects in the course of its work are reproduced at the operator's hand. Dynamic gravity compensation is provided, making the tool feel weightless. The system has been used to demonstrate surgical procedures and is currently being used by Dr. Christoph Kaufmann of the Uniformed Services University of the Health Sciences for a variety of medical training applications. A commercial version of this system is being sold as a laparoscopic robot ('Da Vinci') by Intuitive Surgical, Inc.

- Virtual Anastomosis Trainer (Boston Dynamics, Inc.): This is a virtual workbench-based application for training suturing skills. The user can view a 3D image of a blood vessel whose ends have to be sewn together. The user wears stereoscopic glasses and feel force feedback using a Phantom haptics display. The system tracks performance metrics such as timing, accuracy, tissue damage and instrument placement. The company has preliminary information showing that experienced vascular surgeons perform better on the simulator than do inexperienced medical students, suggesting that the simulator may provide an accurate and valuable training experience.

- CathSim IV Trainer (HT Medical, Inc.) – The system is composed of software modules for specific procedures, a virtual reality view of the anatomy of the arm, user-operated needle, and an AccuTouch™ Tactile Feedback Device. Using this device, the student is able to sense the tactile response of needle and catheter insertion-from the "pop" as the needle enters the skin through entry into the lumen of the vein. The simulator was developed in close collaboration with Dr. Virginia Barker of Plattsburgh State University in New York. CathSim's first software module includes six patient cases offering varying levels of difficulty and complications. Additional modules—such as Central Venous Line Placement and Peripherally Inserted Central Catheterization—will be available. The simulator sells for approximately $6,000, and has been pre-sold to a number of nursing institutions.

- PreOp Bronchoscopy Trainer (HT Medical Systems, Inc.): This is a computer-based system for teaching the motor skills and cognitive knowledge necessary to perform a bronchoscopic procedure. Using real-time computer graphics, including anatomic models developed from patient data and a robotic interface device, force is transmitted through the flexible scope to provide tactile sensations to the user.

- Limb Trauma Simulator (LTS) (Musculographics, Inc.): The LTS is designed to improve the skills and efficiency of first responders (combat lifesavers, combat medics, paramedics) and combat surgeons. The system integrates 3D graphics and force feedback systems with training software that teaches fundamental trauma management skills. LTS was developed for the US Army as an alternative to animal-based and cadaver-based training, and to augment traditional field training. The current version of LTS models a gunshot wound to the leg. The student must characterize the extent of the gunshot injury and control any bleeding. Next, the student inserts an IV catheter into the casualty to replenish the patient's fluids. This product is no longer available as a commercial product.

(C) Surgical Simulation for Combat Trauma Training Skills

This project is supported by the Defense Advanced Research project (DARPA) grant to Drs. Howard Champion and Gerald Higgins (authors of the present report), and is aimed at addressing the lack of combat trauma readiness in the U.S. military by developing computer-based simulation technologies for medical skills training. The project is a

coordinated effort to evaluate the current state of surgical simulation technology and define the engineering and human performance requirements for development of an integrated program of medical simulation training in the military. Specific objectives include assessment of commercially-available and research based systems by a committee of experts, human factors analysis including usability and validation, development of surgical training simulators, task analysis of life-saving and emergency surgery procedures and manipulations for the development of performance metrics, and formation of a permanent advisory committee to the American College of Surgeons, Committee on Trauma. Technical skill metrics have been developed for assessment of performance in critical life-saving procedures including chest tube insertion and cricothyroidotomy. These requirements are being implemented using a hybrid approach, combining the best attributes of physical mannequins and virtual workbench technology with realistic graphics and haptics. System integration efforts are underway with an assessment of current surgical simulation technology and selection of appropriate academic and commercial prototypes and products for inclusion in the training program.

(D) Other Projects

Medical Readiness Trainer (MRT)

The MRT consists of a Human Patient Simulator (HPS; METI) mannequin placed in a CAVE virtual reality environment. This system was developed by Dr. Dag Von Lubitz and colleagues of the Department of Emergency Medicine and the Virtual Reality Laboratory at the University of Michigan. The goal is to simulate a patient in a variety of settings, including an emergency room, operating room and sickbay on a Coast Guard cutter. The CAVE was developed by the Electronic Visualization Laboratory of the University of Illinois at Chicago, and consists of a multi-person, room-sized, high-resolution, 3D video and audio environment. It is essentially a theater 10x10x9 foot, made up of two rear-projection screens for walls and a down-projection screen for the floor. For the MRT, additional medical training content is provided by short video clips, which are displayed on the walls of the CAVE. Virtual reality applications being developed include a burn patient and airway management, in addition to the procedures, which can be performed on the HPS mannequin. Networked tele-training applications supplies the MRT with distance learning capabilities. Future goals include the development of a portable MRT system for deployment and training in the field.

Virtual Medical Trainer - Trauma Patient Simulator (VMET-TPS)

VMET/TPS is an interactive, multimedia, virtual-reality-based simulator that presents the user with a three-dimensional (3D) visual and aural scenario in which a trauma incident has occurred. This system is being developed by Research Triangle Institute of North Carolina. The user may freely navigate within the scene and view the scene and patient from any position. The trauma patient is a 3D virtual model with visible injuries and internal trauma that exhibits medical signs and symptoms with physiological behavior. Mechanisms-of- injury currently represented includes falls, gunshot wounds, vehicle collisions, explosions, and blunt injury. Natural Language Processing allows the user to

speak to the patient and to hear his or her responses. VMET-TPS takes the user through the sequence of trauma-patient assessment, beginning with entering and sizing up the scene, determining level of consciousness, checking the ABCDs, and attending to major life-threatening conditions. The system provides a suite of tools and procedures that include a stethoscope, penlight, bandages, 2-channel physiological monitor, airway and chest-injury management devices, immobilization devices, cervical collars, resuscitation fluids, ventilation devices, and drugs. The system is designed to provide EMTS, medics, corpsmen, medical students, physician with the ability to train and test their assessment and decision-making skills and to develop an appreciation for patient responses to appropriate and inappropriate treatment.

E. Strategic Plan for Medical Simulation in the Military

Although a number of efforts are underway by a variety of entities to address simulation as a means of transferring knowledge in the medical domain, there is currently a lack of an overarching plan, system integration, educational goal-directed and cost-effective matching with available simulation technologies with need. Above all, there is a need to provide system integration and overall architecture, and to do so on a continuous basis with end-user and domain expertise, and knowledgeable interaction with all potential providers of emerging simulation technologies.

1. Critical Elements of the Strategic Plan

These elements are based both upon our work, the work of several academic research programs and commercial ventures, and on the recent Integrated Research Team for Medical Modeling & Simulation meeting, sponsored by the Telemedicine and Advanced Technology Research Center (TATRC) and co-hosted by the United States Army Medical Research & Materiel Command (USAMRMC) and the Simulation Training & Instrumentation Command (STRICOM). This approach emphasizes the importance of developing an integrated program for medical skills training and combat trauma readiness in the U.S. military.

Despite the very extensive use of simulation by non-medical DoD components, current medical simulation efforts in the military are characterized by scattered research and development efforts, university-based research without adequate involvement of the military end-user, procurement of commercial simulator products that are not well integrated into the training program, and the development of limited, single simulator solutions to meet broad training requirements. No systematic efforts have been undertaken to develop and integrate appropriate simulation technology into the medical training curriculum, and there is currently a lack of an overarching plan and system integration to match educational goals with available simulation technologies.

<u>Critical Elements:</u>

(1) Implement the recommendations of this meta-analysis, including training integration, performance assessment, matching fidelity to training needs, involvement of trauma expertise in simulator design, the importance of part task training for procedural skills, development of hybrid and deployable simulators, and the other recommendations that are addressed below.

(2) Involve users in the design and development of medical simulation trainers in the military. The most important strategy for building an efficacious training program in combat medicine is to focus on the needs of the user, employing a 'user-centered' design approach (Whetting et al, 1987). This should include all constituents, including Army, Navy, Air Force and Marines, as well as reserve and guard units. The mechanisms to gather input from users were manifested by the IRT meeting held in February 2000 and other efforts undertaken by contract

personnel. Special emphasis should be placed on training combat medics and other first responder personnel who can most directly benefit from trauma training.

(3) Provide an ongoing mechanism for integration of efforts across military medical domains. These should include, but not be limited to, technology assessment and suitability to user training, integration of simulators within existing training programs in the armed forces, and IRT efforts to continue integration and development efforts.

(4) Develop performance metrics for training and assessment of surgical skills in life-saving procedures. Implement metrics in the simulation-training environment.

(5) Develop formal instructional instruments to evaluate the training efficacy of simulation-based trainers in medicine. These studies should involve instructional design and human factors experts, and should result in credible publication of results in peer-reviewed publications that are acceptable to experts in this arena.

(6) Coordinate military efforts with ongoing activities of the medical modeling and simulation community, including diagnostic imaging and the Visible Human Project (National Library of Medicine), to leverage advances in the computer modeling of human anatomy that can be used to increase the fidelity of visual simulation in medicine.

(7) Increase the network capabilities of existing and planned simulators, to enhance distance learning and Advanced Distributed Learning (ADL) capabilities. It is important that military training sites be integrated into the Abilene network being developed under the auspices of the Visible Human Project.

2. Research and Development Challenges in Medical Modeling & Simulation

The near-term research and development (R&D) challenges for medical simulation and combat trauma training fall into 2 major categories: (1) Basic research in bioengineering to integrate the physical and physiological properties of tissue with accurate computer graphic models of anatomy, and (2) Specific software and hardware development for implementation of trauma skills and procedures in the simulation environment. Unlike visual simulation in other areas of the military, such as terrain modeling or flight controls, medical simulation requires significant R&D funding to increase the validity and fidelity of the training environment. These challenges are shown in Figure #25.

To accomplish these goals, we need a focused R&D agenda, including:

- An overarching strategy
- Military / civilian partnerships
- Public / private partnerships
- A multi-disciplinary, multi-institutional approach
- All constituents served

Basic research and development in medical modeling and simulation should be a high priority for development efforts. Physiological characteristics such as respiration and cardiovascular function must be integrated with realistic anatomical models. Priority should also be placed on biomechanical modeling, including gathering of actual tissue data, physics-based modeling, hemodynamic modeling including bleeding, and methods for real-time tissue deformation. Enhanced visual and haptics ("touch") interfaces for dexterous interaction with the virtual environment should include an emphasis on core technologies supporting virtual workbench and holographic displays.

Figure #25: Basic Research Challenges in Medical Modeling & Simulation: Suggested Short-Term Deliverables and Estimated Budgets

Challenge	Suggested Deliverable	Estimated Budget/Timeframe
Integration of physiological characteristics with anatomical models	Demonstration showing virtual thorax with lung and simple cardiovascular function	$2 million/2002
Biomechanical modeling, including gathering of actual tissue data, physics-based modeling, and methods for real-time tissue deformation	Demonstration of models that can realistically reproduce blunt trauma and device-tissue interaction	$5 million/2005
Hemodynamic modeling	Demonstration of CFD (computational fluid dynamics) model that can simulate and predict blood flow	$5 million/2005
Medical image modeling, including automated segmentation and registration	Demonstration of accurate, rapid and automated reconstruction of three dimensional model from medical image dataset (eg, MR, CT)	$10 million/2005
Interactive holographic display	Holographic display that has sufficient functionality to support realistic interaction, including haptics and tissue deformation	$7.5 million/2007
High resolution haptics displays	Glove display with tactile and proprioceptive resolution approximating gloved hand; Virtual workbench and medical device displays with appropriate torque and translation characteristics	$15 million/2010
Virtual Human	Integrated human models for various applications (eg, risk assessment, predictive pharmacodynamics) including genome, morphome, physiome and proteome	$100-500 million/2015

Medical Modeling & Simulation Workshop – July, 2000

Near-term R&D needs in medical modeling and simulation have been identified by the National Academy of Sciences and others as high priorities include:

- The need to catalogue and archive current biomedical models
- Developmental of common computational and user interfaces
- Development of shared resources to create multi-level and multi-scale biomedical models

These priorities are being addressed by an upcoming meeting, "Modeling & Simulation in Medicine: Towards and Integrated Workshop", to be held at the National Library of Medicine on July 20-21, 2000 in Bethesda, MD. The goal of the workshop is to bring together researchers from biology, medicine, computer science and engineering to assess current user needs, foster cross-disciplinary collaboration, and define the future research agenda.

This workshop has been organized to address the following questions:

(1) What is the current state of model development in biomedical modeling and simulation? What models have been developed and what are their characteristics?

(2) What are the needs and requirements for development of a common system for biomedical model development in simulation? Can existing and planned formats, programming languages and computational tools provide for integration of models from diverse sources for development of more comprehensive simulators? If not, what steps are needed to develop a unified standard for development?

(3) Given a defined set of needs and requirements, can the participants provide a path for development of a common modeling language that can be used for subsequent development of biomedical models?

Specific Goal of the Workshop:

The goal of the workshop will be to develop a report that will spur integration of biological models from different domains in biology, and lay the groundwork for subsequent development of a common modeling language in biology and medicine. A report will be published from the workshop. The first section of the report will provide a description of the current state of research in biomedical modeling and will contain a survey of existing models, toolkits and authoring languages. The second section of the report will detail the results of the workshop, including recommendations for overcoming current integration problems, and development of broad solutions to model integration including the possibility of a common modeling language.

3. Need to Determine the Training Efficacy of Medical Simulators

One of the biggest unmet needs in the development of an effective program in medical simulation-based training in the military is the complete lack of efforts to determine the effectiveness of simulation training applications in both military and civilian sectors. For example, in the Combat Trauma Patient Simulator (CTPS) program using the Human Patient Simulator (METI), very little attention has been paid to a determination of whether this simulator actually provides useful training in trauma skills. Although there is a small component to test simulator efficacy in Phase IV of the CTPS, this function was going to be performed by a co-developer of the system – clearly a problem for providing an objective determination of training efficacy.

Medical personnel often assume that they can make a subjective determination of training efficacy, because medical training is often based on mentorship and skill evaluation derived from subjective opinions of senior personnel. However, several studies have shown that "negative training" effects can be missed by subjective efforts to evaluate the efficacy of training simulators. Thus, standard human factors approaches should be used for evaluating the utility of simulation-based trainers in medicine.

This needs to be a priority of the fledging efforts of the IRT program. Technology development, including new visual and haptics displays, is irrelevant without proof that medical simulators train end-users in the skills needed to perform trauma procedures.

Based on the experience with flight and military simulation, a process by which medical simulators may be designed and validated is shown in Figure X (Higgins et al, 1997). The design process insures that the simulator being developed is a genuine replication of the actual medical procedure, and this process relies heavily on the input from surgeons acquainted with the surgical procedure being simulated. Validation is a process by which the simulator is proven to provide the elements necessary for positive training and thus can be used for certification. The main elements of the process are described below (see Figure #25):

<u>User Needs Analysis</u>

The question of user needs is addressed by defining the optimal "feature sets" that the user requires in an application to complete the necessary tasks. The emphasis is on determination of a minimum feature set for efficient training and performance evaluation. Human factors engineers use a variety of approaches to address these issues, relying most heavily on one-to-one interviews and video recordings of individuals using a given application, the classic "scenario based training analysis". Another approach is to first build the application, then embed performance tracking software into the application, and attempt to gain quantitative information about the population of users from the computer's database. Expertise is also gathered from medical consultants.

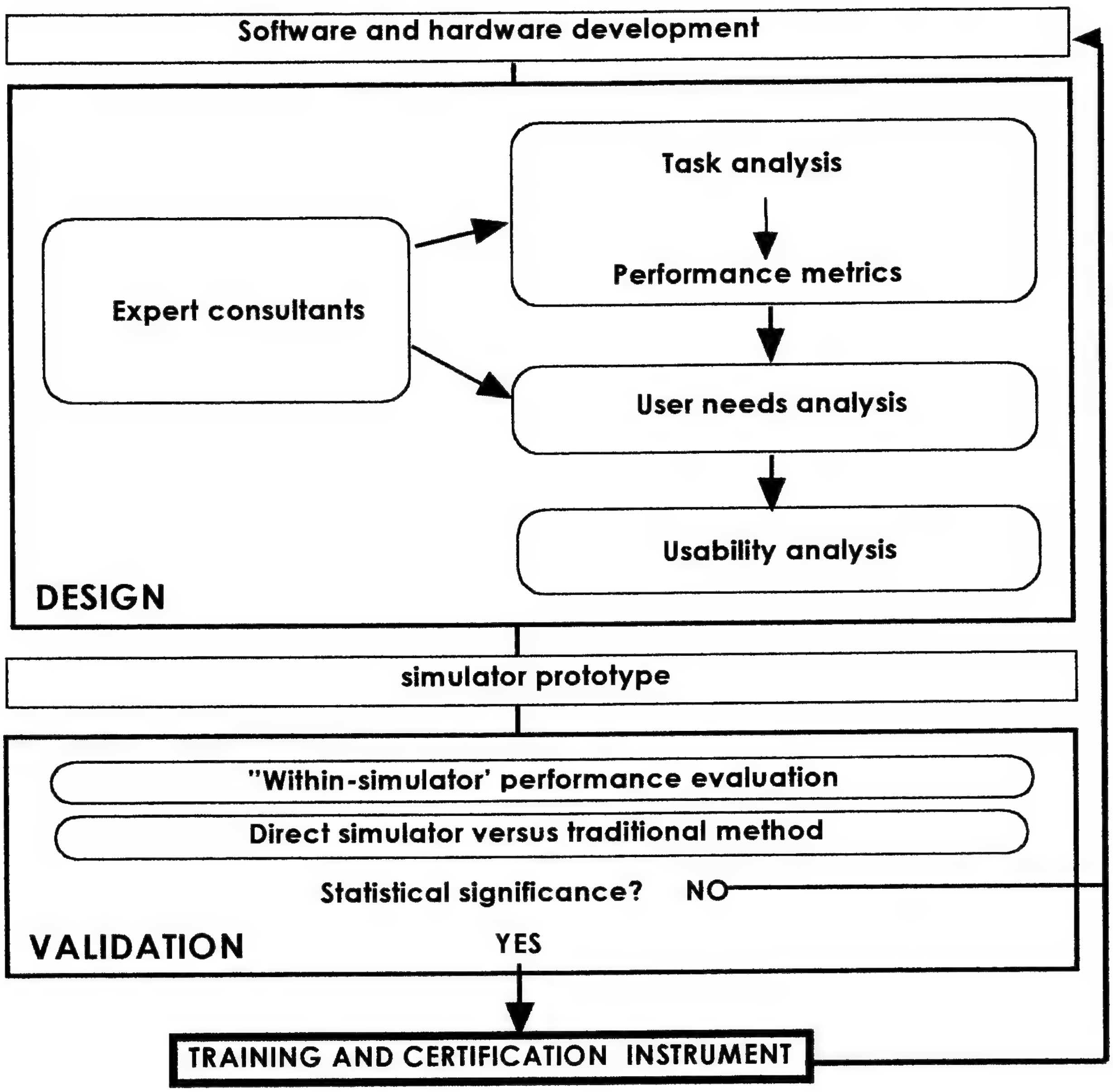


Figure #26. This outlines a process by which a medical simulator can be validated as a training and certification instrument. If the simulator is not determined to be efficacious, then additional software and hardware modification is required.

<u>Content and Content Matter Expert Consultation</u>

A critical part of the design process is to have ongoing input from surgeons with expertise in the requisite specialty, to both guarantee simulator realism, and to provide 'face validity' for the larger community of surgeons. One approach to this need is to form advisory boards in specific surgical specialties to provide both subject matter expertise and to check on the authenticity of the simulated procedure. This insures that the educational content is clearly of the highest standards. A critical element of medical simulation is the content.

The technology is in an early development stage, and will continue to mature to provide increasing levels of realism as computational power and device sophistication improve. However, during the time that the simulators evolve to the point that they exhibit completely realistic human physical and physiological behavior; the educational content must be appropriate to the current level of technology. For example, with current computational power the visual fidelity will be less than realistic. In addition, new technology brings new educational opportunities. The new and *different* educational content(de) should benefit from the *difference* in the technology (dt), such that the curriculum has added value beyond the same material presented with previous technology. For example, compared to books, video tapes bring animation and motion, so the content using video should emphasize aspects such as demonstrating processes that occur over time (rather than simply show a series of still photos as if turning pages of a book or showing slides). Simulator technology brings real time interactivity and "infinite perspective", which invites learning through discovery. Therefore, the de should compliment the dt: the added educational value can be attained by creating highly interactive 3D models which provide an "infinite number of perspectives" (i.e. the anatomical structures can be seen from a limitless number of angles, from outside or inside, etc) and that invites the student to learn by exploring and interacting with the anatomy. Unless this approach is taken, the new (and often more expensive) technology will simply be a more polished version of the same information, and therefore not provide additional educational value for the additional cost.

<u>Usability analysis</u>

The goal here is to insure that a given training simulator, or more general computer application for that matter, can be used as desired and required. Graphical user interface (GUI) optimization is often a priority. For example, if one of the simulator's features is too difficult, too easy, or too annoying to the user over repeated uses, this may irritate the user sufficiently that they will not use the application. In addition, the interface must not interfere with performance assessment, that is, the interface should not be designed in a manner that the interface degrades performance, resulting in poor performance because of the interface and not the student's skills.

<u>Validation</u>

This occurs during prototype development or at a relatively complete stage of simulator development. There are widely divergent approaches to measuring how well a simulator trains an individual to perform a task. Specific approaches, ranging from the simplest and cheapest to the most complex, include:

- *Within-simulator performance evaluation*: This is the most common approach used for testing the training effectiveness of flight simulators. The hypothesis is that the degree to which the simulation contains the visual and haptic information necessary for effective training should be reflected in the quality of the performance observed when it is used to perform a simulated procedure. For example, for medical simulators, it is possible to take surgeons who are 'expert' at a specific procedure,

and see how well they perform on the simulator. These data are then evaluated using statistical tests designed specifically to compare simulation performance with actual surgical performance in the real world. These data can then be used to determine transference rates.

- *Direct simulator versus traditional method testing:* In this verification process, the performance of a student trained only on a simulator would be compared to a control student tested using traditional mentoring procedures. For medical simulation, a 'scaled-down' version of complete training transfer could be used, comparing students trained both with simulators and using traditional methods versus those trained with traditional methods alone. This includes comparison to pelvic trainers, mannequins, tissue simulants, cadaver, live animal and strict surgical mentoring procedures. The final determinant of training efficacy is the performance of the student on actual patients.

4. Advanced Distributed Learning (ADL): Implications for Medical Simulation

A recent workshop entitled identified key research areas that need to be developed to produce the goal of reaching the "ADL in 2012" vision of the Department of Defense. The ADL initiative focuses on developing technologies and applications that can provide "anywhere, anytime" training for military personnel. Special emphasis is placed on training cognitive readiness and decision-making skills, providing virtual tutors for the trainee, creating valid measures of performance that can be assessed at a distance, creating models of individual and group performance, and understanding and predicting human behavior in complex and unstructured environments.

Four key research areas that address the educational design process, ranging from requirements analysis and course development to delivery and assessment, are:

- <u>Intelligent Computer Aided Instruction (ICAI):</u> ICAI focuses on the development of an empirical foundation of how individuals and teams develop expertise to guide the selection of ADL instructional alternatives and provide an accurate assessment to enable appropriate follow-on, remedial instruction, and system improvement.

- <u>Authoring Tools (AT):</u> Authoring tools examines the development of tools to quickly and appropriately retrieve and effectively teach digitally coded knowledge and skills.

- <u>Distributed Simulations (DS):</u> Distributed simulations look at the problem of generating realistically performing models of individual behavior, virtual team members, adversaries, friendly forces, and non-combatants in a realistic environment across the ADL network.

- <u>Dynamic Learning Management (DLM):</u> DLM addresses the infrastructure and architecture needed to ensure ADL interoperability and security.

These issues have tremendous relevance for training military medical personnel such as combat medics and trauma surgeons. The need to provide skills training and performance assessment to geographically-dispersed personnel, for example, on ships or airplanes, and/or under pre-deployment conditions, is especially important for maintenance of the complex skills required for combat trauma procedures.

The following research objectives, selected from a larger group of research objectives identified in the ADL workshop report, are the most critical ADL issues for future development of medical skills training in the military.
Intelligent Computer Aided Instruction (ICAI):

- Understanding the evolution of expertise and cognitive decision-making skills in complex, ill-structured environments –Penetrating the "fog of war". The first responder and the trauma surgeon often have to perform highly skilled cognitive, perceptual and motor tasks under conditions of extreme stress and unpredictable dynamics. The ability to train expert performance in such as environment requires an understanding of human behavior in the face of uncertainty and stress.

- Capture effective behaviors of outstanding human instructors. Medical trainers and content experts differ widely in their ability to provide effective training. Medicine is a hierarchal training system in which expertise and ability are often concentrated in a few senior practitioners. If the expertise from these individuals could be captured and provided to trainees using a 'virtual tutor' model, then much broader and effective training could be provided to all, not just a select few.

- Develop techniques for assessing cognitive workload and strategies for mitigating adverse effects of workload. The battlefield triage environment may present so many cognitive challenges that personnel may become overloaded and unable to function. Strategies that allow the practitioner to "unburden" cognitive workload could greatly enhance individual and team performance in trauma medicine.

- Develop comprehensive models and measures of individual and team capabilities and performance. Model individual training and experience histories to predict ease of learning and retention of needed task-specific knowledge and skills. Develop a tutoring capability sensitive to curriculum, level of expertise required, and the learner's motivation, ability, and preparation. Models of individual and team performance need to be developed for specific medical procedures and skills. Performance of individual trainees, based on their capabilities and experience, can then be compared 'expert' practitioners to optimize performance assessment and training. Intelligent medical tutors can be used as aids to enhance performance taking into account the needs of individual trainees.

- Develop hardware and associated displays for augmented reality systems. Augmented reality displays have been developed for medical procedures in domains such as image-guided surgery. Extension of this technology into the medical training domain can provide the student with a virtual tutor that can be

overlaid on real or virtual medical environments. Thus, a trainee performing a procedure for the first time can be guided by a virtual assistant that can provide procedural guides and coaching.

Authoring Tools:

- Create authoring tools for curriculum, simulations, assessment, system management, and intelligent tutors. There are currently few domain-specific authoring tools available for the creation of training applications in medicine. One high priority goal, described in more detail below, will be to develop a common modeling language, where biological entities are represented as software objects that can be reconfigured into different training simulations using XML or similar languages.

- Provide automated feedback of individual and system performance data to centralized facilities. Eventually, objective measures of medical performance captured using computer simulation and training applications, will serve as the basis for accreditation and progression in medicine. The development of technologies for automated performance tracking and storage will help provide this functionality.

- Develop reusable components of ICAI and performance coaches. Allow rapid reconfigurability of instructional materials (scenarios, problems, cases, exercises) in accordance with task requirements. The variability inherent in procedural medicine and different patient subtypes means that treatment strategies may differ widely even for similar disease and pathology states. Thus, the trainee needs to be provided with a range of case scenarios and treatment options, configurable based on end-user training requirements.

Distributed Simulation Environments for Instruction:

- Rapidly generate scenarios consistent with mission rehearsal and deployment needs. In trauma medicine, the battle environment can determine the kinds of wounds that are encountered and the logistics of triage. The ability to provide a simulation for mission rehearsal that takes into account variables such as setting, types of weapons and individual combatant characteristics would greatly aid the far forward medical teams in preparation for treatment of wounded soldiers.

- Enable the interchange of real and virtual team members to support anywhere/anytime training delivery. The development of teleconsultation, telementoring and telesurgical systems can help provide the medic and trauma surgeon with enhanced capabilities, both during training and actual performance of medical procedures.

- Develop models for immersive training and education. Much effort has been invested in the development of immersive "surgical simulation" training applications that use virtual reality, stereoscopic displays and haptics interfaces to provide the trainee with so-called "suspension of disbelief". Little effort has been focused on understanding what is important for providing effective training using such immersive training modalities.

Dynamic Learning Management (DLM):

- Efficient methods for extracting and coding human expert knowledge. This is a challenge in medicine, where expert knowledge needs to be conveyed to trainees. Expert medical knowledge is complex and usually transmitted in a "mentoring" relationship where the trainee serves as an apprentice to the expert, and instruction can take a variety of forms. No standard approaches have been used for extracting and coding this information, and much more development needs to be done in this arena.

- High bandwidth ubiquitous network. The Internet-2 project, which includes the "Redline Collaboratory" Next Generation Internet project of the National Library of Medicine is one example of a high bandwidth network which is being configured to link military training sites (Fort Sam Houston, Fort Bragg, USUHS) with civilian networks that can provide medical training applications.

- Create decomposable, reconfigurable, and shareable knowledge objects Use knowledge now stored in static databases or buried in system designs to create dynamic distributable instruction. Establish a common format for acquisition, storage, maintenance, retrieval, and application of knowledge bases. There is a need to develop software objects representing biological components, for applications such as web-based distance learning and distributed simulation of biological systems. This will include a vocabulary and classification scheme for biological components such as molecules, cells, tissues, organs and organisms and how these biological components can be translated into software objects. Focus should be placed on development of a basic set of protocols for defining objects, how the objects will communicate with each other, and how these components can be combined and distributed for a web-based learning application. The work will exploit existing network-based technologies, including XML and COBRA, and creation of platform-neutral and reusable courseware, based on existing sources of content such as the Visible Human Project and Human Genome Project. The goal will be to design a rational object hierarchy for biological components .The development can be done in a gradual fashion, and it is recommended that all constituents be accommodated in this process. The first step will be to define the short-term goal of the process and the desired outcome. The second goal is to identify the general hierarchy of the biological objects in a way that can be used by object brokering software. The next step will be to develop a 'working' (not final) classification and labeling scheme.

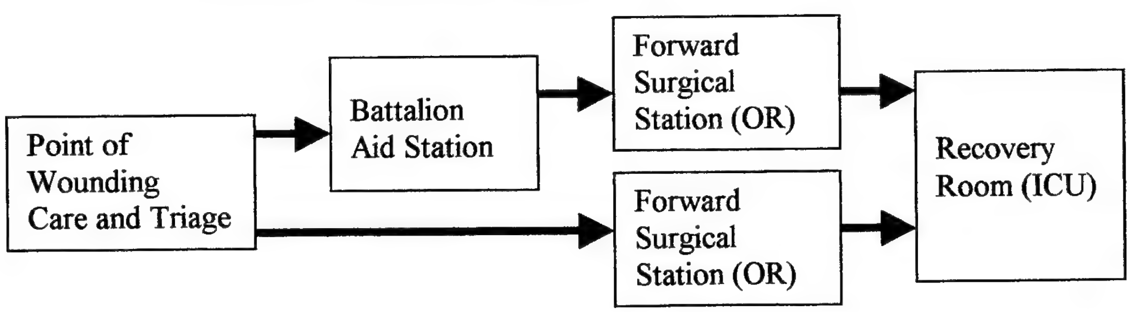
> <u>Describe well-defined processes for cognitive task analysis including standard output formats.</u> Although cognitive task analysis has been applied to medical procedures for deconstruction into components, there is still no standard approach for procedural task analysis, including output formats.

5. The Joint Combat Trauma Training Simulation (JOCOTTS) Center

One overarching vision is to develop a number of Joint Combat Trauma Training Simulation (JOCOTTS) centers available throughout the United States. A typical configuration might consist of 30 to 50 stations involving a range of simulation technologies which can be used to train and assess care provided by medics, medical officers and surgical teams at the point of wounding, emergency resuscitation, triage, resuscitative surgery and post-operative recovery or critical care. Simulators can be adjusted to the educational and training needs of the trainee. Metrics would be used to discriminate between novice, expert and intermediate skill level, and to identify and focus on training shortcomings. Virtual environment technology will be used to provide physical and psychological stressors to emulate the resource-constrained combat environment that degrades user performance.

The end-result will be the development and implementation of multiple JOCOTTS centers, including the AMEDD Center and School, Ben Taub Hospital, USUHS, Fort Bragg and other sites .The Joint Combat Trauma Simulation Trauma Training Center will be designed to implement basic principles derived from the military simulation training experience, including user-centered design, cost efficacy, performance metrics and technology selection based on medical simulation requirements. The first deliverable of the project should be a prototype which will demonstrate simulation technology for trauma training, including procedures such as the control of wound hemorrhage and needle thorancentesis. Subsequent efforts could then be focused on the development of 4 - 5 Combat Trauma Simulation Training Centers located at various sites throughout the U.S. The Center will be designed to provide the foundation for subsequent medical simulation training efforts in the military, and could be linked using the Redline Collaboratory network described above.

Overview of Proposed JOCOTTS Configuration



A prototype JOCOTTS center could be developed for the Ben Taub hospital in Houston, Texas. The Simulation Center would be organized into stages, based on the configuration of trauma care in the field and the associated medical personnel treated wounded soldiers. These include 'Point-of-Wounding'(egg, combat medics), Battalion Aid Station (medics,

nurses and physicians), Forward Surgical Station (surgeons and associated personnel), Recovery Room/ICU (physicians, nurses and other health personnel). Patient scenarios could be derived from recent combat incidents duplicating not only the wound, but also the tactical milieu.

(6) KEY RESEARCH ACCOMPLISHMENTS

- Identification of key features of simulation-based training, including transfer-on-training, fidelity, performance assessment and part-task training, that will be critical for development of an effective simulation-based training program in medicine in the military. This analysis is based on a review of 141 relevant papers over the past 50 years, and this bibliography has been annotated according to key features.

- Meta-analysis of the military simulation literature showing that military simulators produce a very positive training effect (field effect of 0.44). This is preliminary finding which is currently being verified and incorporated into a larger article.

- Review and analysis of current simulation programs, simulators and simulation budgets in the military, including Army, Navy and Air Force, and other DoD components.

- Development of 13 general guidelines based on previous military simulation training studies coupled with 13 specific recommendations for medical simulation for combat trauma training. These recommendations are based on the military simulation experience, and address the requirements for an integrated training approach, with performance assessment, case scenario development and simulator fidelity matched to the cognitive, perceptual and motor attributes of the user.

- Development of a strategic plane for medical simulation in the military, including:

    - Explanation of the differences between non-medical and medical simulation, and why medical simulation needs to be guided by medical trainers in the military,

    - Identification of medical training requirements for military medical personnel, including the 91W combat medic, Special Operations combat medic and physicians. The increasing reliance on surgical skills among first responders in the military emphasizes the need to use medical simulation-based training for medical skills.

    - Review of medical simulation in the civilian and military sectors, including a description of commercial products, university research and development efforts and selected medical simulation projects in the military. Greater emphasis needs to be placed on matching simulation technology to the cognitive, perceptual and motor needs of the user.

    - A 'Strategic Plan' that highlights important issues that need to be addressed for future and ongoing integration. These include identification of critical elements, including basic research and development challenges, approaches for evaluation of medical simulation training efficacy, future requirements for distributed simulation in the military (Advanced Distributed Learning (ADL)) and proposed development of Joint Combat Trauma Training Simulation (JOCOTTS) Centers.

(7) REPORTABLE OUTCOMES

– **Manuscripts, abstracts, presentations:**

(A) Presentations

H.R. Champion and G.A. Higgins

- AMSUS Meeting, December 1999
- Briefing for Dr. Sue Bailey (Undersecretary of Health Affairs, DoD), Jan, 2000
- Briefing for Dr. Bob Foster (Director, BioSystems, DDR&E), January 2000
- Integrated Research Team for Modeling & Simulation, February 2000

G.A. Higgins

- NDIA, December 2000
- Society of Laparoscopic Surgeons, December 2000
- Office of Device Evaluation, FDA, May 2000

(B) Papers

1. Higgins, G.A. and H.R. Champion, The Military Simulation Experience: Charting the Vision for Simulation Training in Combat Trauma, *in preparation*
2. Higgins, G.A., L.J. Hettinger and H.R. Champion, Meta-analysis of training transfer using military simulation, *in preparation*
3. Higgins, G.A., L.J. Hettinger and H.R. Champion, Design of a training simulator for medical skills proficiency, *in preparation*

– **Informatics such as databases:**

Development of a database of publications on military simulation, with a focus on studies of training efficacy, performance assessment, fidelity and part-task training.

– **Funding applied for based on work supported by this award:**

1. BAA proposal entitled, "Integration of Simulation Training for Combat Trauma Readiness"
2. Preproposal, "Combat Trauma Registry and Teaching File"

- Other

Design and organization of a meeting entitled, "Modeling & Simulation in Medicine: Towards an Integrated Framework", to be held at the National Library of Medicine on July 20-21, 2000. This meeting will include top researchers in human modeling and simulation along with experts from DoD and the NIH to develop a roadmap for continuing research and development efforts in this domain.

(8) CONCLUSIONS

The military simulation experience provides significant guidance for the development of an effective medical simulation program for training combat medics and physicians. A detailed analysis of the literature and review of current military simulation efforts shows that simulation is an effective and cost efficient approach to training military personnel. Recommendations based on the military experience include the importance of training integration, performance assessment, hybrid simulation technologies, fidelity for user acceptance, focus on the user and not the technology, part task trainers for procedural training, virtual environments for spatial training, case scenarios for performance enhancement, advanced instructional features, flexible delivery platforms, and the need for periodic evaluation of training efficacy and cost-effectiveness. One important finding is that senior trauma personnel should guide system integration. Simulator development should emphasize trauma-specific skills and procedures. Current efforts using minimally-invasive techniques and single simulator applications may have limited value for training the combat medic and trauma surgeon.

Combat trauma training represents the best application of simulation-based training of medical personnel in the military. System integration and overall architecture must be guided using an integrated technology approach, on a continuous basis with end-user and trauma expertise, and knowledgeable interaction with all providers of existing and emerging simulation technologies. Basic scientific research should be focused on computer graphics, haptics, biomechanical modeling and computational fluid dynamics to provide higher fidelity and more clinically relevant models for simulation training. Renewed emphasis should be placed on the development of a 'functional' human model, based on the Visible Human Project at the National Library of Medicine. A critical need is to conduct formal instructional and human factors analysis of medical simulators being used currently in the military and civilian sectors, to assess the training efficacy and cost-effectiveness of these fledging systems. Integration of Advanced Distributed Learning (ADL) features into the system will increase the utility of distributed simulation-based training, and the development of Joint Combat Trauma Training Simulation (JOCOTTS) centers are recommended to concentrate simulation trainers in existing military training sites.

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